FUZZY LOGIC BASED AUTOMATIC PLANT WATERING SYSTEM

A MASTER THESIS

BY

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DEPARTMENT OF ELECRICAL AND COMPUTER ENGINEERING

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

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DEPARTMENT OF ELECRICAL AND COMPUTER ENGINEERING

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DECLARATION

I hereby declare that this thesis entitled **"Fuzzy Logic Based Automatic Plant Watering System"** was done by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or procession qualification.

Author Signature, Date

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Witnessed by:

Name of the Advisor: Signature, Date

Dr. Eng. Getachew Alemu____

CERTIFICATE

This is to certify that the thesis prepared by **Mr. Hunegnaw Ylkal Truneh** entitled **"Fuzzy Logic Based Automatic Plant Watering System"**, submitted in fulfillment of the requirement of the degree of Master of Science compiles with the regulation of the University, and meets the accepted standards with respect to originality and quality.

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ABSTRACT

In this thesis, design of fuzzy logic based automatic plant watering system for the crop maize is proposed. The health of a plant or crop is influenced by many factors; like wind speed and direction, radiation, temperature and humidity and so on. The plant watering requirement for any crop is the amount of water that must be applied to meet the crop's evapotranspiration (ET) needs. The longer the growth period of the crop is the higher the water requirement. The dry moisture value is also the higher water requirement. Due to this, automatic plant watering system is the best solution for managing of water and to increase the production rate of the crop.

Automatic plant watering system was done based on Fuzzy logic controller, which has three input parameters and one output parameter. The input parameters are moisture value of the soil (with range of 0 to 100%), evapotranspiration difference (with range of -10 to 10 mm/day) and month after sowing of the crop (with range of 0 to 140 day). The output parameters is the duration of valve opening (with range of 0 minute to 30 minute). Penman-Monteith equation is used to compute the actual evapotranspiration of the specific crop from climate conditions. The difference between actual (calculated) evapotranspiration and the desired evapotranspiration is one of the input parameter for the fuzzy interface system. The evapotranspiration estimation has four input variables. These are humidity, temperature, radiation and wind speed.

The duration of valve opening is gradually increased with the decreasing of Moisture value, mid-season of the crop sowing period and the decreasing of evapotranspiration difference. When the evapotranspiration difference is highly negative, the moisture value of the soil is dry and the month after sowing of the crop is in mid stage, the duration of valve opening was very long. And also when the evapotranspiration difference is highly positive, the moisture value of the soil is wet and the month after sowing of the crop is in initial stage and late stage, the duration of valve opening was zero or very short.

Keywords*:* Fuzzy logic, Evapotranspiration, Fuzzy interface system, Penman-Monteith equation, plant watering

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Hunegnaw Ylkal

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LIST OF ACRONYMS

AggMethod	Aggregation method
AndMethod	The logic and method
DefuzzMethod	Defuzzification method
EQ	Equal
ET	Evapotranspiration
ETo	Reference evapotranspiration
FAO	Food and Agricultural Organization
FLC	Fuzzy logic controller
I/p	Input
ImpMethod	Implementation method
LN	Large negative
LP	Large positive
MF	Membership function
NumInputs	Number of inputs
NumOutputs	Number of outputs
NumRules	Number of rules
O/p	Output
OrMethod	The logic or method
RH	Relative humidity
sms	Message
SN	Small Negative
SP	Small positive
V-long	Very long
V-short	Very short
VVT	Variable valve timing

CHAPTER ONE

INTRODUCTION

1.1. Background

Plant watering system is artificial use of water to land or soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and re vegetation of disturbed soils in dry areas and during periods of insufficient rainfall. Additionally, plant-watering system has a few other uses in crop production, which includes protecting plants against frost, suppressing weed growing in grain fields and helping in preventing soil consolidation. Plant watering is a system that is installed in agricultural land to improve the efficient use of water [1].

The continuous extraction of water from earth is reducing the water level due to which lots of land is coming slowly in the zones of un-irrigated land. This problem can be rectified if we use fuzzy logic based automated plant watering system in which the plant watering will take place only when there will be acute requirement of water [1].

In the field of agriculture, plant watering system plays key role. Effective utilization of water resources as well as preventing water losses is equally important. For this estimation of water, requirement of the crop is needed. The plant watering requirement for any crop is the amount of water that must be applied to meet the crop's evapotranspiration (ET) needs. The amount of ET includes water that is needed for both evaporation and transpiration. Evaporation occurs from all wet surfaces, including soil, water and plants. Transpiration is the evaporation from plant through the leaves stomata. Both evaporation and transpiration occur in response to climate demand [5]. The highest water crop needs are thus found in areas which are hot, dry, windy and sunny. The lowest water needs are found when it is cool, humid, cloudy and with little wind or no wind. The influence of the climate on crop water needs is given by the reference crop evapotranspiration (ETo). The ETo is usually expressed in millimeters per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop. Crops need high amount of water at middle stage of their growth [24].

Plant watering systems are divided in to two as manual and automatic plant watering system.

A. Manual plant watering system

Manual plant watering systems are easy to handle, require no technical equipment and generally cheap But they need high labor inputs. Beside these systems, there are many other methods for manual plant watering, which are easy to install and simple to use [1, 2].

B. Automatic plant watering system

An automatic plant watering system refers to the operation of the system with no or just a minimum of manual intervention besides the surveillance. And an automatic plant watering system was done using wireless sensor based automatic plant watering system; microcontroller based automatic plant watering system, and finally based on artificial intelligent automatic plant watering system. Almost every system can be automated with the help of timers, sensors or computers or mechanical appliances. It makes the plant watering process more efficient and workers can concentrate on the other important farming tasks. On the other hand, such a system can be expensive and very complex in its design and may needs experts to plan and implement it. And it has advantages over manual plant watering system [3]

An automation of plant watering systems has several positive effects. Ones installed, water distribution on fields of small-scale gardens is easier and does not have permanently controlled by an operator [3].

The **Benishangul-Gumuz Region** is highly covered by the crop Grains, specifically Sorghum and Maize and covers 59829.26 hectare and 31045.76 hectare, respectively. The maize yields 20.11 quintal per hectare and the Sorghum yields 15.94 quintal per hectare. As can be seen Table 1.2, from Benishangul-Gumuz Region, Assosa zone is also highly covers by the crop Grain: Sorghum and Maize covers 24383.68 hectare and 8852.58 hectares, respectively. The Maize yields 18.41 quintal per hectare and the Sorghum yields 14.77 quintal per hectare as shown tables below. The maize is more yields (18.41 quintal per hectare) than sorghum. Area, Production and Yield of Crops for Private Peasant Holdings for Meher Season 2007/2008 (2000 E.C) [4] is given in Table 1.1. Area, Production and Yield of Crops for Private Peasant Holdings for Meher Season 2007/2008 (2000 E.C) [4] is given in Table 1.2.

Table 1.1: Area, Production and Yield of Crops for Private Peasant Holdings for Meher Season 2007/2008 (2000 E.C) Benishangul-Gumuz Region [4]

Crop	**Number of holders**	**Area in hectare**	**Production in quintal**	**yield (qt / ha)**
Grain	159439	191989.85	2628891.10	
Cereals	157062	142470.32	2244617.83	
Teff	39696	18870.52	205102.25	10.87
Barley	6047	1275.85	16474.09	12.91
Wheat	6917	3425.70	49714.10	14.51
Maize	131253	31045.76	624379.50	20.11
Sorghum	108509	59829.26	953679.37	15.94
Finger millet	51392	27518.99	387430.30	14.08
Rice	1698	421.13	6806.48	16.16

Table 1.2: Area, Production and Yield of Crops for Private Peasant Holdings for Meher Season 2007/2008 (2000 E.C) Assosa [4]

Crop	**Number of holders**	**Area in hectare**	**Production in quintal**	**yield (qt / ha)**
Grain	68309	53856.10	662420.41	
Cereals	67770	39537.92	577988.44	
Teff	18058	3682.95	26030.61	7.07
Barley	*	*	-	-
Wheat	-	-	-	-
Maize	60114	8852.58	162964.30	18.41
Sorghum	56150	24383.68	360091.68	14.77
Finger millet	15348	2576.25	28307.85	10.99

1.2. Statement of the Problem

The health of a crop is influenced by many factors; like wind speed, rainfall, radiation, temperature and humidity. Some arid places in Ethiopia need water for their crops using modern techniques of plant watering system. From Benshangul-Gumuz region, Assosa zone is one of these places. This zone is highly covered by the crop Grain, specifically Sorghum and Maize. And covers 24383.68 hectare and 8852.58 hectares, respectively. The Maize yields 18.41 quintal per hectare and the Sorghum yields 14.77 quintal per hectare. The maize is more yields (18.41 quintal per hectare) than sorghum [4]. The farmers have been farming this crop, from June first to half of November based on the local rain season of Assosa in case study area but it is not enough only by keeping the rain to farms the crop. They need a technology to farms the crop based on influence factors. Plant watering system plays key role. Effective utilization of water resources as well as preventing water losses is equally important. Due to this, automatic plant watering system is the best solution for managing water and to increase the production rate of crops. Fuzzy logic controller is very effective techniques for this processes for which either no mathematical model exists or the mathematical model is severely nonlinear, because FLC's can easily approximate a human expert's control behaviors that work fine in such ill-defined environments [9]. The fuzzy logic is used to increase assists in decision-making. In other case, the crops will die if there are not get enough water. The gardener must use automatic plant watering system to ensure the conditions of their crops are in the good health.

1.3. Objectives of the thesis

1.3.1. General objective

The general objective of this thesis is to design plant watering system based on fuzzy logic controller by taking row data from Assosa for crop maize.

1.3.2. Specific objectives

- ✓ Design the fuzzy logic controller based on evapotranspiration difference, moisture value and length of sowing period.
- ✓ Estimate or calculate evapotranspiration from the sensor measurements humidity, radiation, wind speed and temperature.
- ✓ Determine fuzzy control rules of fuzzy logic from membership function

- ✓ Determining the duration of valve opening

1.4. Methodology

The procedure that follow to complete this thesis are as follows. After reviewing various related materials, the area of the research was selected that is Benshangul-Gumuz region specifically around Assosa. The environmental data was taken from three consecutive years 2017, 2016 and 2015 of Assosa from [22] to get the desired evapotranspiration value. Specifically, this thesis concerns for the crop maize. This crop farms from June first to half of November based on the local rain season of assosa. The evapotranspiration are calculated using the Penman–Monteith equation.

The evapotranspiration varies in average from 4.3 to 18.6 mm/day based on the local rain season of assosa from three consecutive years. The climate condition between June and October is better for the farming of maize. The evapotranspiration values for those moths are between 4.3 to 10.6 mm/day. Therefore, between 5 to 10 mm/day in average for three consecutive years is better to use as a desired reference evapotranspiration. Therefore, the desired evapotranspiration is 8 mm/day in average.

The software used in this thesis are MATLAB 2017a. Penman-Monteith equation was used to compute the actual evapotranspiration of the specific crop from climate conditions. The difference between actual (calculated) evapotranspiration and the desired evapotranspiration is one of the input parameter for the fuzzy interface system.

The four different input values act as sensors in a function of matlab simulink to calculate the evapotranspiration. The four input variables are humidity, temperature, radiation and wind speed measurements for estimating or calculating the evapotranspiration.

In this thesis Fuzzy logic controller from MATLAB toolbox was used because Fuzzy can handle real life uncertainties and therefore ideal for nonlinear, time varying and hysteretic system control [7, 8].

The fuzzy logic controller have input parameters and output parameter. The input parameters for the fuzzy logic controller are evapotranspiration difference (with the range of -10 to 10 mm/day), moisture value (with rage of 0 to 100 %) and the sowing period of the crop (with the range of 0 to 140 days). The output parameter of the fuzzy logic controller is the duration of the valve opening (with the range of 0 to 30 minute).

Member ship function was used to define the input variable as well as output variable. For this thesis, the membership functions are triangular and trapezoidal because of simple formulae and computational efficiency both triangular and trapezoidal MFs are used especially in real time applications [35].

The evapotranspiration difference input has five fuzzy variables and the moisture value input has three fuzzy variables whereas the sowing period input has four fuzzy variables, and used to develop Linguistic Rules. The products of these rules are then aligned to determine the duration of valve opening of the actuator.

As a result by have been applied analysis based on the different values to input parameters of moisture, evapotranspiration difference and month after sowing, the corresponding crisp output of the fuzzy logic on the valve was determined.

1.5. Significant of the thesis

The automatic plant watering system saves the following.

- ✓ Avoiding watering at the wrong time of day, reduce runoff from overwatering saturated soils.
- ✓ The plant watering system will operate by less man power
- ✓ Automation eliminates the manual operation of opening or closing valves,
- ✓ The plant watering process starts and stops exactly when required, thus optimizing energy requirements
- ✓ Increase the production
- ✓ The plants or crops will save from illness

1.6. Thesis Organization

This thesis is organized into five chapters. In the first chapter, background and justification of this thesis work and the objectives to be achieved are introduced. Chapter 2 summarizes the efforts of previous studies related to this works. Chapter 3 presents the Evapotranspiration estimation and the Fuzzy logic design of plant watering system. Chapter 4 presents the results and discussions of Fuzzy logic based automatic plant watering system. Chapter 5 concludes the study and suggests for future work.

CHAPTER TWO

RELATED WORK

There are many efforts made in the area of plant watering system. “A fuzzy logic based irrigation management system in arid regions applied to the State of Qatar” was done by F. Touati, et al [2]. In this, paper a practical solution based on fuzzy logic controller (artificial intelligence). In arid regions like Qatar, the time and duration of plant watering is key to achieving sustainable supply of waters. First, it describes a microcontroller-based system that collects data from soil moisture, ambient temperature, and solar radiation. Then the fuzzy logic controller takes these three inputs, and based on the created rules table for a given crop, it produces the desired time and duration of plant watering system. This result showed that the developed system rigorously balances the amount of water that is lost through evapotranspiration as predicted by *Penman–Monteith* model, which is adapted by the FAO (Food and Agricultural Organization). The aim of this work [2] is to minimize the evapotranspiration and the plant watering should be in the morning, around the time of sunrise or sometimes even at night [12]. This strategy will reduce the amount of water wasted with the traditional techniques. The result of this work [2] is stated that the fuzzy logic controller avoids plant watering system during high temperatures throughout the day in order to reduce evapotranspiration. It also selects the appropriate time by referring to the base of fuzzy rules. What is missing in this paper [2]? Where, all design and implementation phases are described for the state of Qatar. At high temperature the system does not operate watering system but, at high temperature the crop or plant needs high water and in arid lands like Qatar, evaporation losses caused by wind can be eliminated [13] but wind is a main factor for evapotranspiration and in my work, it is one factor of evapotranspiration. In this study, we used four different values act as sensors of wind speed, temperature, radiation and soil moisture.

A work done by V. S. Rahangadale and D. S. Choudhary in [5], proposed a design for fuzzy logic based plant watering controller using penman-Monteith equation. Here, difference between actual and desired evapotranspiration is one of the input parameter to the fuzzy inference system. Month after sowing of a crop was also an important parameter taken into consideration. As there is no mathematical model exists for both parameters, fuzzy logic technique is most suitable for modeling [5]. The aim of this research [5] work is to help in plant watering management by estimating water requirement of the crop using FAO Penman-Monteith equation and implementing a model of plant watering controller using advanced soft computing methods. Initially conventional on-off plant watering controller was modeled. Further advancement in controller design has been done with the help of fuzzy logic controller. Error value of evapotranspiration is acting as one input to fuzzy logic controller. Month after sowing of a crop is another input parameter for fuzzy controller. Result of this work [5] is stated, as Output waveform for conventional on-off plant watering controller is shows the fluctuation in the output of controller. Also there is no other way to add the intelligence of adding second parameter of crop sowing period. The fuzzy controller output is varying according to the error value of actual and desired evapotranspiration. What is the gap in this research [5] ? It was done based on only two inputs means evapotranspiration difference and crop sowing period but it does not concern about moisture of the soil. And also basically it was done for rice (six month sowing period).

An Intelligent Automatic Irrigation System was also done by S.Tale and Sowmya p. in [14]. This research states that, when the farmers are away from the crop land for a long day there is a need of physical watering [14]. In this work microcontroller is the heart of the undertaking all information changing and controlling of outside peripherals can be controlled by microcontroller. When the soil moisture is dry, the field catches fire, animals enters agricultural field's and temperature goes high then the sensors sends message to microcontroller and after receiving message from microcontroller water motor will switch on automatically. What is the gap in this research [14]? It was done based on only humidity and temperature measurements and when one of the measurement changes the microcontroller sends high signal or low signal to the output device. When the soil moisture is dry the motor switch on automatically and also when the temperature goes high the motor will switch on automatically. And, it is not managing the water because of high temperature. It does not manage water.

A similar effort made by by V. N. R. Gunturi in [15] is to provide automatic plant watering which helps in saving money and water. The entire system is controlled using 8051 microcontroller, which is programmed as giving the interrupt signal to the sprinkler. Temperature and humidity sensors are connected to internal ports of micro controller via comparator. Whenever there is a change in temperature and humidity of the surroundings these sensors senses the change and gives an interrupt signal to the microcontroller and thus the sprinkler is activated. The system provides with several benefits and can operate with less labor. The system supplies water only when the humidity in the soil goes below the reference value. Due to the direct transfer of water to the roots water conservation takes place and helps to maintain the moisture to soil ratio at the root zone constant to some extent. Thus, the system is efficient and compatible to changing the environment [15]. What is the gap in this research [15]? it was done based on only humidity and temperature measurements and when one of the measurement changes microcontroller sends high signal or low signal to sprinkler to activated or to sprinkler to deactivated respectively. And, it is not managing the water because of high temperature, when temperature is increases evaporation will increase.

Table 2.0.1: Summary of related work

Authors	**Approach**	**Sensors used and Parameters considered**	**Gap observed**
F. Touati, and K.Benhamd	Microcontroller and Fuzzy logic based	✓ Soil moisture ✓ Temperature ✓ Radiation	Avoids watering at high temperature Evaporation loss caused by wind eliminated
V. S. Rahangadale and D. S. Choudhary	Fuzzy logic based	✓ Month after sowing ✓ Evapotranspiration difference	Moisture of the soil is not considered and it was done for rice.
Sarika Tale and Sowmya P.	Microcontroller based	✓ Temperature ✓ Soil moisture ✓ Infrared	When the soil moisture is dry the motor switch on and also when the temperature goes high the motor will switch on automatically
V. N. R. Gunturi	Microcontroller based	✓ Temperature ✓ Humidity	It is not managing the water because of high temperature

CHAPTER THREE

SYSTEM MODELING AND DESIGN

3.1. System description

The Fuzzy logic based automatic plat watering system consists of different parts: Input variables for Evapotranspiration calculation, evapotranspiration estimation or calculation, comparator, desired evapotranspiration, fuzzy logic controller, length of sowing period, moisture measurement and duration of valve opening as illustrated in Fig.3.1.

3.1.1. Input variables for Evapotranspiration calculation:

Input variables for Evapotranspiration calculation includes four blocks that are

- ✓ Temperature measurement
- ✓ Humidity measurement
- ✓ Net radiation measurement and
- ✓ Wind speed measurement

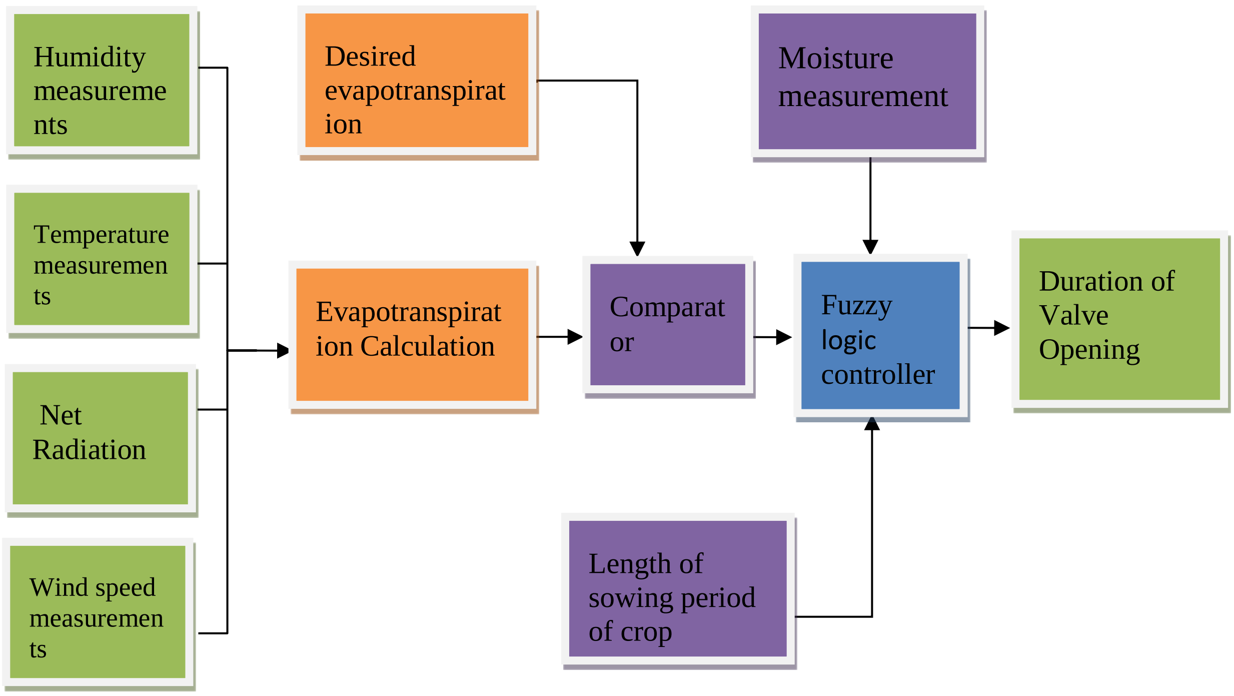

Fig. 3.1: Block diagram of the fuzzy based plant watering system

All these variables are fed to evapotranspiration (ETo) estimator block which computes actual value of evapotranspiration. Input variables temperature, humidity, net radiation and wind speed are simulated as sinusoidal signal and frequency is set according to 24 hrs (one day). A frequency of 0.2618 rad/h. This frequency is given according to a period of 24 h: 0.2168 rad/h = $2\pi/\mathbf{T}=2\pi/24$.

3.1.1.1. Temperature measurement

The temperature of an object is the amount of hotness or coldness in the environment that is generated by an object or system, allowing us to "sense" or detect any physical change to that temperature producing either an analogue or digital output. Temperature Sensor collects real-time data from the environment. It is the mean daily air temperature at 2 m height [°C]. This variable has a sine wave with amplitude of 4 ºC; a constant bias (offset) of average value of the temperature from the measurement. We can use temperature sensor with range of 0 to +50 ºC. The SF-110 is one of these sensors and the temperature measurement range is -40 to +70 ºC with an accuracy of $\pm$ 0.1 ºC from 0 to +70 ºC [36].

3.1.1.2. Humidity measurement

Water vapor is the gaseous state of water and invisible to the human eye. The amount of water vapor that is needed to achieve saturation increases as the temperature increases. Humidity is the amount of water vapor present in the air. Humidity sensor is collects real-time data from the environment. The humidity sensor just senses the moisture of the soil. Humidity measurement is used to estimate the reference evapotranspiration.

Relative humidity is measured directly with hygrometers. This variable has a sine wave with amplitude of 2%; a constant bias of average value of the Relative humidity from the measurement. We can use relative humidity sensor with range of 0 to 100%. Thin film polymer capacitor with the range of 0-100% with temperature operating range -50 ºC to 50 ºC is one of the sensors.

3.1.1.3. Net radiation measurement

The net radiation (R_n) is the difference between the incoming net shortwave radiation and the outgoing net longwave radiation or in other words, Net radiation is the difference between incoming solar radiation and outgoing infrared radiation. Earth absorbs incoming solar radiation and outgoing infrared radiation is lost to space [18]. High radiation will accelerate evapotranspiration [16].

The energy emitted by the sun is often called short-wave radiation because approximately 99% of the sun's energy is emitted in the short wavelengths. The percentages of the total energy emitted in various wavelengths from the sun are [17]:

- ✓ 9% in the ultraviolet wavelengths
- ✓ 45% in the visible
- ✓ 46% in the near infrared.

Of this radiation, on average [17]:

- ✓ 20% is absorbed in the atmosphere by clouds and gases
- ✓ 31% is reflected back to space
- ✓ 49% is absorbed by the earth's surface (on a sunny day - 75%, on a cloudy day - 15%).

Net radiation is the balance between the energy absorbed, reflected and emitted by the earth's surface. The total daily value for R_n is usually positive over a period of 24 hours, except in extreme conditions at high latitudes. Solar radiation can be measured with pyranometers, radiometers or solarimeters. Net longwave and net shortwave radiation can be measured by recording the difference in output between sensors facing upward and downward. Where pyranometers are not available, solar radiation is usually estimated from the duration of bright sunshine. This instrument records periods of bright sunshine by using a glass globe that acts as a lens. The quantity of heat conducted into the soil, G, can be measured with systems of soil heat flux plates and thermocouples or thermistors [18].

The Thermopile pyranometers is used to measure the short wave radiation measurement with ± 2 % Error Due to Clouds. The net radiation variable has a sine wave with amplitude of 2%; a constant bias of average value of the Net radiation from the measurement.

3.1.1.4. Wind speed measurement

Wind is characterized by its direction and velocity. Wind direction refers to the direction from which the wind is blowing. For the computation of evapotranspiration, wind speed is the relevant variable. Wind speed is a fundamental atmospheric quantity and caused by air moving from high pressure to low pressure, usually due to changes in temperature**.** Wind speed is one of the inputs for the reference evapotranspiration. An anemometer is one of the tools used to measure wind speed. To compute ETo the wind speed at 2 m above the ground surface is necessary.

As wind speed at a given location varies with time, it is necessary to express it as an average over a given time interval. Wind speed is measured with anemometers. The anemometers commonly used in weather stations are composed of cups or propellers, which are turned by the force of the wind. By counting the number of revolutions over a given time period, the average wind speed over the measuring period is computed. The wind speed variable has a sine wave with amplitude of 3 mph; a constant bias of average value of the wind speed from the measurement.

3.1.2. Evapotranspiration Estimation

Water is used by crop through evaporation from the soil or water surface and by transpiration through the leaves. In the early stages of crop growth, most water is used through evaporation. The combined use of Evaporation and Transpiration is called evapotranspiration (ET). The total evapotranspiration varies from crop to crop. This quantity depends on seasonal conditions such as temperature, humidity, wind and sunlight hours as well as the length of the growing period. The Food and Agriculture Organization (FAO) of the United Nations has been proposed the famous and well-known Penman-Monteith equation, Allen et al. [18] as the most adequate method of calculating the reference evapotranspiration (ETo). The crop water requirements which is equal to the evapotranspiration (ET) for any crop can be calculated from the equation below

$$\mathrm{ETc} = \mathrm{Kc} \times \mathrm{ETo} \tag{1}$$

Where,

ETo = Reference evapotranspiration [mm.day^{-1}]
ETc = Water requirement of the crop
Kc= Crop coefficient

The crop reference evaporation (ETo) is determine from meteorological data. The FAO penman-Monteith method is maintained as the sole standard method for the computation of ETo from meteorological data. Evapotranspiration (ET) is the combination of evaporation and transpiration of hydrological cycle. Both evaporation and transpiration show the effect on hydrological cycle. Climatic conditions have direct influence on the evapotranspiration. The evapotranspiration as calculated with Penman–Monteith equation (2) and which has been adapted by the FAO (Food and Agricultural Organization) so far [18] is given by:

$$ETo = \frac{0.408\Delta\,(R_n - G) + \Upsilon \frac{900}{T + 237} u_2(e_a - e_s)}{\Delta + \Upsilon(1 + 0.34u_2)} \tag{2}$$

Where,

ETo = Reference evapotranspiration [mm.day^{-1}]
Δ = Slope vapor pressure curve [kPa.°C^{-1}]
R_n = Net radiation at the crop surface [MJ.m^{-2}.day^{-1}]
G = Soil heat flux density [MJ.m^{-2}.day^{-1}]
Υ = Psychometric constant [kPa.°C^{-1}].
T = mean daily air temperature at 2 m height [°C]
u_2 = wind speed at 2 m height [m.s^{-1}]
$(e_a - e_s)$= Saturation vapor pressure deficit [kPa]
e_a = Actual vapor pressure [kPa]
e_s= Saturation vapor pressure [kPa]

The slope of saturation vapor pressure curve (Δ, kPa/°C) can also be obtained in terms of air temperature (T, °C) as given by Murray [19] in the following formula.

$$\Delta = \frac{4098[0.6108 \exp\left(\frac{17.27\mathrm{T}}{\mathrm{T} + 273}\right)]}{(237.3 + \mathrm{T})^2} \tag{3}$$

Also, the following best fit equation given by [20], it can be used for computation of Δ.

$$\Delta = 0.00021501\mathrm{T}^2 - 0.00025132\mathrm{T} + 0.061309 \tag{4}$$

Saturated air vapor pressure e_s [kPa], can be obtained from the equation

$$e_s = 0.6108 \exp\left(\frac{17.27\mathrm{T}}{\mathrm{T} + 237.3}\right) \tag{5}$$

The equation is reduced and can be expressed as given by [20]. It is used here for estimating saturated air vapor pressure e_s.

$$e_s = 7.167 \times 10^{-5}\mathrm{T}^3 + 7.167 \times 10^{-4}\mathrm{T}^2 + 0.061309 \times \mathrm{T} + 0.57075 \tag{6}$$

Vapor pressure of the actual air e_a [kPa] depends on saturated air vapor pressure e_s and relative humidity RH that is defined as the ratio of actual vapor pressure in the air (e_a)

to that of saturated air (e_s) at the same temperature. Relationship between these three parameters is given by

$$e_a = \frac{e_s \times RH}{100} \tag{7}$$

Where,

RH = Relative humidity
e_s = saturated vapor pressure

Soil heat flux density [MJ/m^2 day] G is directly depending on net radiation; hourly value can be approximated as 0.1 times of net radiation.

$$G = 0.1 \times R_n \tag{8}$$

The psychometric constant, γ is given by,

$$\gamma = \frac{C_p P}{\varepsilon \lambda} \tag{9}$$

$$\gamma = \frac{1.005(\frac{KJ}{Kg°\mathbf{C}}) \times 101.3KPa}{0.622 \times (2.51 - 0.00236 \times T(°\mathbf{C}))} \tag{10}$$

Where,

γ = psychometric constant [kPa $°C^{-1}$]
P = atmospheric pressure [kPa]
λ = latent heat of vaporization, 2.45 [MJ kg^{-1}]
C_p = specific heat at constant pressure, 1.013 10^{-3} [MJ kg^{-1} $°C^{-1}$]
ε = ratio molecular weight of water vapour/dry air = 0.622

3.1.3. Desired reference evapotranspiration

The reference evapotranspiration (ETo) is an important agro metrological parameter which has been used in water requirement of crop [21]. Reference evapotranspiration is calculated using penman-Monteith equation by taking the average annual measured values of temperature, humidity, radiation, and wind speed around Assosa.

In this works to get the desired evapotranspiration value, the environmental data was taken from three consecutive years 2017, 2016 and 2015 of Assosa in tables and figures below. Form Fig.3.2 to Fig.3.4 and from Table 3.1 to Table 3.9 indicate the environmental data that was collected from Assosa in three consecutive years. Fig. 3.2 and Table 3.1 to Table 3.3 indicate annual temperature measurements at assosa zone in the year 2017 to 2015 [22]. The data is used to calculate the reference ETo by taking average temperature of the month. The average temperature of the month is given in the tables below.

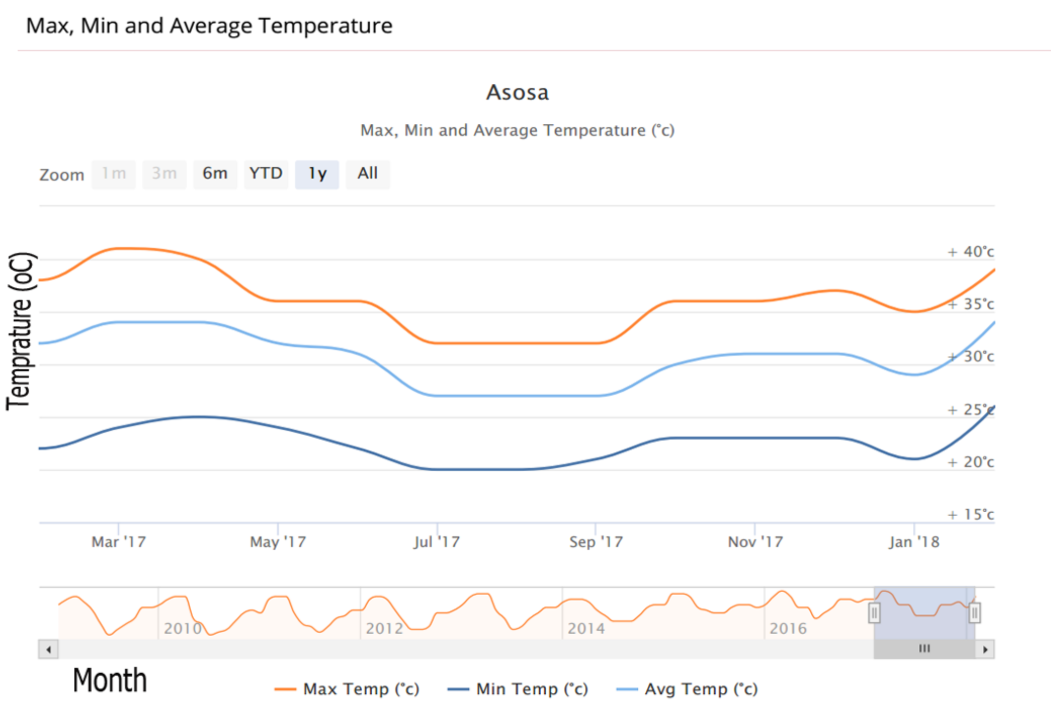

Fig.3.2: Assosa area annual temperature in the year 2017 [22]

Table 3.1: Assosa area annual temperature in the year 2017 [22]

Month	Feb, 17	Mar, 17	Apr’ 17	May’ 17	Jun’ 17	Jul’ 17	Aug’ 17	Sep’ 17	Oct’ 17	Nov’ 17	Dec’ 17	Jan’ 18
Max Temp (^{o}C)	38	41	40	36	36	32	32	32	36	36	37	35
Min Temp (^{o}C)	22	24	24	24	22	20	20	21	23	23	23	21
Avg Temp (^{o}C)	32	34	34	32	31	27	27	27	30	31	31	29

Table 3.2: Assosa area annual temperature in 2016 [22]

Month	Feb’ 16	Mar’ 16	Apr’ 16	May, 16	Jun, 16	Jul, 16	Aug ,16	Sep’ 16	Oct’ 16	Nov’ 16	Dec’ 16	Jan’ 17
Max Temp (^{o}C)	39	41	39	35	35	31	33	35	38	38	37	38
Min Temp (^{o}C)	22	25	24	23	22	20	20	21	22	21	22	22
Avg Temp (^{o}C)	33	35	34	31	30	27	28	30	32	33	31	32

Table 3.3: Assosa area annual temperature in 2015 [22]

Month	Feb 15	Mar' 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 15	Oct 15	Nov' 15	Dec' 15	Jan' 16
Max Temp (°C)	40	40	39	35	34	33	33	35	36	36	35	36
Min Temp (°C)	23	24	23	23	22	21	20	21	22	21	20	20
Avg Temp (°C)	33	34	33	30	29	29	28	30	31	31	29	30

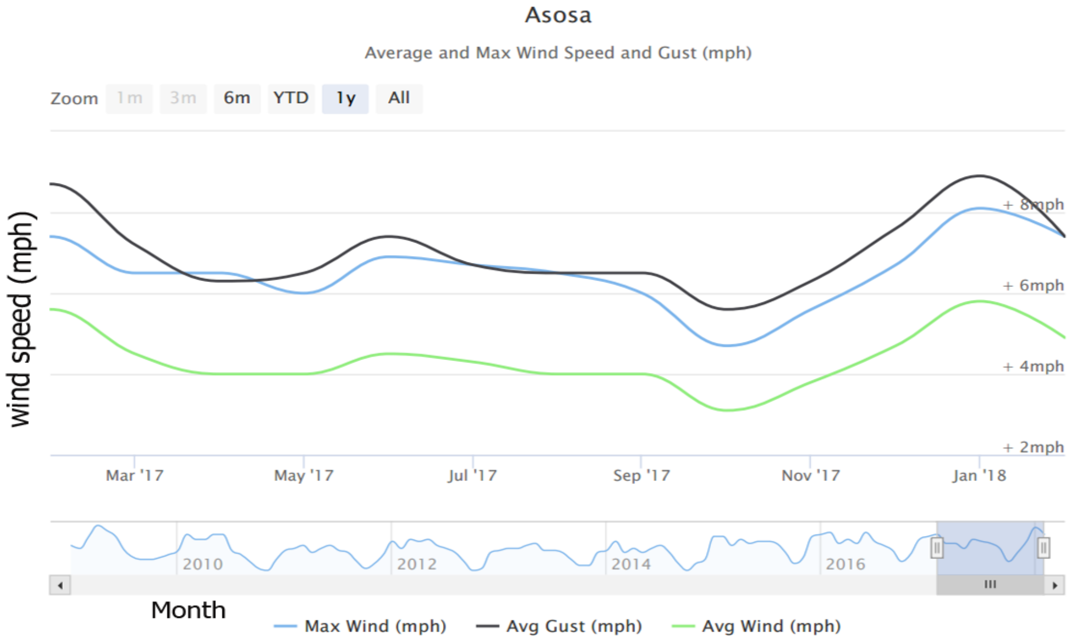

Fig.3.3: Assosa area annual wind speed in the year 2017 [22]

Fig.3.3 and Table 3.4 to Table 3.6 indicate annual wind speed measurements at assosa zone in the year 2017, 2016 and 2015 [22]. In this thesis, the data is used to calculate the reference evapotranspiration by taking average wind speed of the month. The average wind speed of the month is given in tables below.

Table 3.4: Assosa area annual wind speed in the year 2017 [22]

Month	Feb’ 17	Mar’ 17	Apr’ 17	May’ 17	Jun’ 17	Jul’ 17	Aug’ 17	Sep’ 17	Oct’ 17	Nov’ 17	Dec’ 17	Jan’ 18
Max Wind (mph)	7.4	6.5	6.5	6	6.9	6.7	6.5	6	4.7	5.6	6.7	8.1
Avg Gust (mph)	8.7	7.2	6.3	6.5	7.4	6.7	6.5	6.5	5.6	6.3	7.6	8.9
Avg Wind (mph)	5.6	4.5	4	4	4.5	4.3	4	4	3.1	3.8	4.7	5.8

Table 3.5: Assosa area annual wind speed in the year 2016 [22]

Month	Feb’ 16	Mar’ 16	Apr’ 16	May’ 16	Jun’ 16	Jul’ 16	Aug’ 16	Sep’ 16	Oct’ 16	Nov’ 16	Dec’ 16	Jan’ 17
Max Wind (mph)	7.6	6.5	6.9	6.5	7.6	6.7	6.3	5.8	4.7	5.4	6.9	7.2
Avg Gust (mph)	8.7	6.3	6.7	6.7	7.8	6.7	6.5	6.5	5.8	6.9	8.3	8.5
Avg Wind (mph)	5.6	4	4.5	4.3	4.9	4.3	3.8	3.8	3.1	4	5.1	5.4

Table 3.6: Assosa area annual wind speed in the year 2015 [22]

Month	Feb’ 15	Mar’ 15	Apr’ 15	May’ 15	Jun’ 15	Jul’ 15	Aug’ 15	Sep’ 15	Oct’ 15	Nov’ 15	Dec’ 15	Jan’ 16
Max Wind (mph)	7.2	6.3	6.9	6.5	6.7	6.7	6.5	5.6	4.5	5.1	7.2	9.2
Avg Gust (mph)	7.8	6	6.7	6.7	7.4	7.2	6.3	5.8	5.4	5.8	8.7	7.4
Avg Wind (mph)	4.9	3.8	4.5	4.3	4.7	4.5	3.8	3.6	3.1	3.4	5.4	5.8

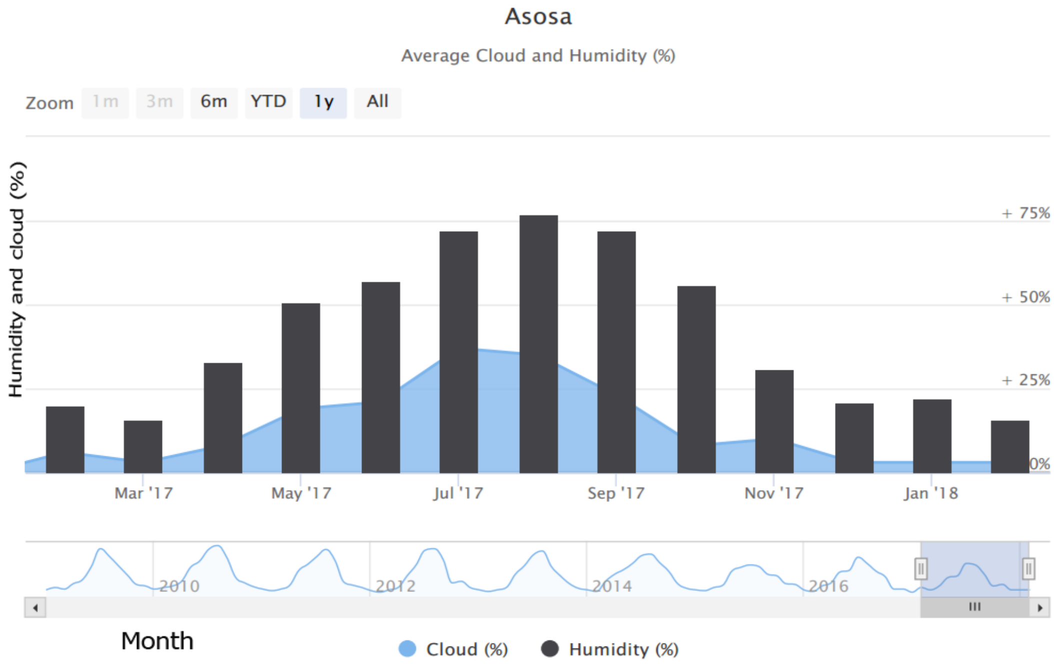

Fig.3.4: assosa area annual humidity and cloud in the year 2017 [22]

Fig.3.4 and Table 3.7 to Table 3.9 indicate annual humidity measurements and annual cloud measurements at assosa zone in the year 2017, 2016 and 2015 [22]. In this thesis, the data is used to calculate the reference evapotranspiration by taking average humidity and average radiation of the month. The average humidity and average radiation of the month is given in tables below.

Table 3.7: Assosa area annual humidity and cloud in the year 2017 [22]

Month	Feb, 17	Mar, 17	Apr, 17	May, 17	Jun, 17	Jul, 17	Aug, 17	Sep, 17	Oct, 17	Nov, 17	Dec, 17	Jan, 18
Humidity (%)	21	18	33	51	57	72	77	72	56	31	21	22
Cloud (%)	6	3	8	19	21	37	35	23	8	10	3	3
Radiation (%)	43	46	41	30	28	12	14	26	41	39	46	46

Table 3.8: Assosa area annual humidity and cloud in the year 2016 [22]

Month	Feb’ 16	Mar’ 16	Apr’ 16	May’ 16	Jun’ 16	Jul’ 16	Aug’ 16	Sep’ 16	Oct’ 16	Nov’ 16	Dec’ 16	Jan’ 17
Humidity (%)	18	25	37	58	61	75	72	65	55	27	28	20
Cloud (%)	1	8	12	26	28	45	37	27	20	4	4	0
Radiation (%)	48	41	37	23	21	4	12	22	29	45	45	49

Table 3.9: Assosa area annual humidity and cloud in the year 2015 [22]

Month	Feb’ 15	Mar’ 15	Apr’ 15	May’ 15	Jun’ 15	Jul’ 15	Aug’ 15	Sep’ 15	Oct’ 15	Nov’ 15	Dec’ 15	Jan’ 16
Humidity (%)	17	26	31	58	67	70	72	68	63	40	32	22
Cloud (%)	2	6	9	27	32	35	33	23	21	11	10	3
Radiation (%)	47	43	40	22	17	14	16	26	28	38	39	46

Specifically, this thesis concerns for the crop maize. This crop farms from June first to half of November based on the local rain season of assosa. The Average evapotranspiration of the month is given below for the three consecutive years. As illustrated in the Table 3.10 the highest evapotranspiration was calculated from November. This value is 15.3 mm/day. The lowest evapotranspiration was calculated from August. This value is 4.3 mm/day in the year 2017 and in Table 3.11, the highest evapotranspiration was calculated from November. The value of highest evapotranspiration was 18.6 mm/day. The lowest evapotranspiration was 4.8 mm/day, which was recorded in July 2016. At high evapotranspiration value, the water requirement for the specific crop is high and at low evapotranspiration value, the water requirement for the specific crop is low.

Table 3.10: From June to November the ETo calculation of the year 2017

Month	Jun' 17	Jul' 17	Aug' 17	Sep' 17	Oct' 17	Nov' 17
Humidity (%)	57	72	77	72	56	31
Radiation (%)	28	12	14	28	41	39
Wind speed	4.5	4.3	4	4	3.1	3.8
Temperature	31	27	27	27	30	31
ETo (mm/day)	**10.6**	**5.4**	**4.3**	**5.2**	**8.0**	**15.3**

Table 3.11: From June to November the ETo calculation of the year 2016

Month	Jun' 16	Jul' 16	Aug' 16	Sep' 16	Oct' 16	Nov' 16
Humidity (%)	61	75	72	65	55	27
Radiation (%)	21	4	12	22	29	45
Wind speed	4.9	4.3	3.8	3.8	3.1	4
Temperature	30	27	28	30	32	33
ETo (mm/day)	**9.5**	**4.8**	**5.3**	**7.4**	**9.2**	**18.6**

As illustrated in Table 3.12 the highest evapotranspiration was calculated in November. This value is 12.4. The lowest evapotranspiration was calculated in August, year 2015 whose value is 5.3 mm/day.

Table 3.0.12: From June to November the ETo calculation of the year 2015

Month	Jun'15	Jul'15	Aug'15	Sep'15	Oct'15	Nov'15
Humidity (%)	67	70	72	68	63	40
Radiation (%)	17	14	16	26	28	37
Wind speed	4.7	4.5	3.8	3.6	3.1	3.4
Temperature	29	29	28	30	31	31
ETo (mm/day)	**7.5**	**6.7**	**5.3**	**6.6**	**7.2**	**12.4**

From paper **[23]** the maize mean water requirement during initial-stage is 1.3 mm/day, however within this stage slight variation in ETc is observed across the locations, where it varies between 1.1 to 1.7 mm/day. During developmental-stage, ETc is increases and it varies between 1.4 to 5.0 mm/day, whereas across the locations it varies between 1.0 to 5.7 mm/day. During the mid- stage season mean water requirement is also increases and varies between 5.0 to 6.6 mm/day whereas across locations it varies between 3.8 to 8.3 mm/day. During the late-season stage, ETc decreases progressively up to end of crop season. The ETc at this stage varies between 6.4 to 2.5 mm/day whereas across the locations it varies between 7.8 to 1.8 mm/day. The stage wise mean ETc for maize is 20.1, 94.5, 232.9 and 89.5 mm during initial-stage, dev-stage, mid- stage season and during late- stage season respectively. The total water requirement of maize is varying with its climate condition. For example in the paper **[23]** the total water requirement higher at Bharuch (520.5 mm) whereas lower at Khedbrahma (380.7 mm). It is seen that the amount of water requirement increases with the stage of crop and across the locations. Variation in water requirement is more in mid-season stage followed by developmental stage of crops across the locations and less variation is observed in initial stage **[23]**.

The crop coefficient of the maize at different stages is as followed. During the initial stage, season of the maize crop coefficient is 0.3. At the development stage, season the crop coefficient is 1.2. At the mid stage season, the crop coefficient is 1.2 and at the late stage season the crop coefficient is 0.35 **[23]**.

Generally, the evapotranspiration varies in average from 4.3 to 18.6 mm/day based on the local rain season of assosa from three consecutive years. This evapotranspiration is good for the farming of maize. The climate condition between June and October is good for the farming of maize. The evapotranspiration values for those moths are between 4.3 to 10.6 mm/day. Therefore, between 5 to 10 mm/day in average for three consecutive years is better to use as a desired reference evapotranspiration. Therefore, the desired evapotranspiration is 8 mm/day in average**.**

3.1.4. Comparator

The purpose of the comparator compares the evapotranspiration estimation and the desired evapotranspiration. The Error value (evapotranspiration difference) is used as one input of the fuzzy logic controller.

3.1.5. Fuzzy logic Controller

Fuzzy set theory can handle real life uncertainties and therefore ideal for nonlinear, time varying and hysteretic system control. The membership functions are distributed according to the possible values of each variable after fuzzification [7, 8]. There is no mathematical model exists for all parameters. Therefore, fuzzy logic technique is most suitable for modeling. Fuzzy logic controller behaves like human brain so it is better with doing this controller.

The input parameters for fuzzy logic controller are

1) The evapotranspiration difference
2) The soil moisture value
3) Length of sowing period of crop.

Fuzzy logic controller decides the valve opening time.

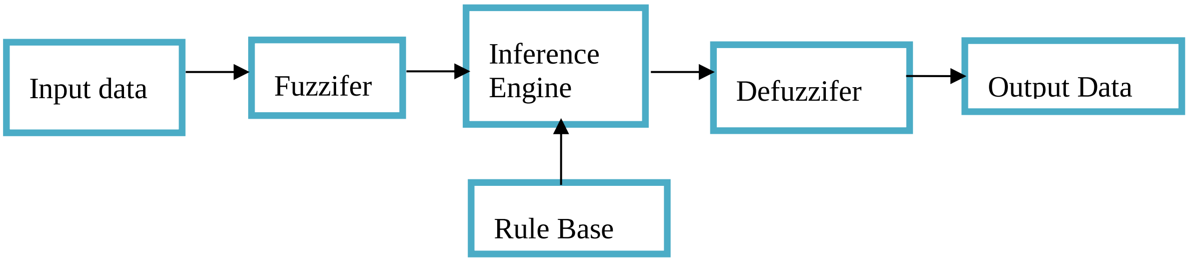

Fig.3. 5: Fuzzy logic controller structure [5]

The fuzzy system could control the watering quantity by using fuzzy control rules to limit opening and closing time of valve. Mamdani inference algorithm will employ as fuzzy control model for this closed-loop control system [5]. Fuzzy controller will design by MATLAB fuzzy logic toolbox.

3.1.5.1. The FIS Editor

The fuzzy logic control system modeled in Matlab is being illustrated in Fig.3.6. In this figure, the input variables are defined as moisture value, evapotranspiration difference (error) and month after sowing. The fuzzy Inference System is called the maize using Mamdani method. Lastly, the output variable is shown that is the duration of valve opening.

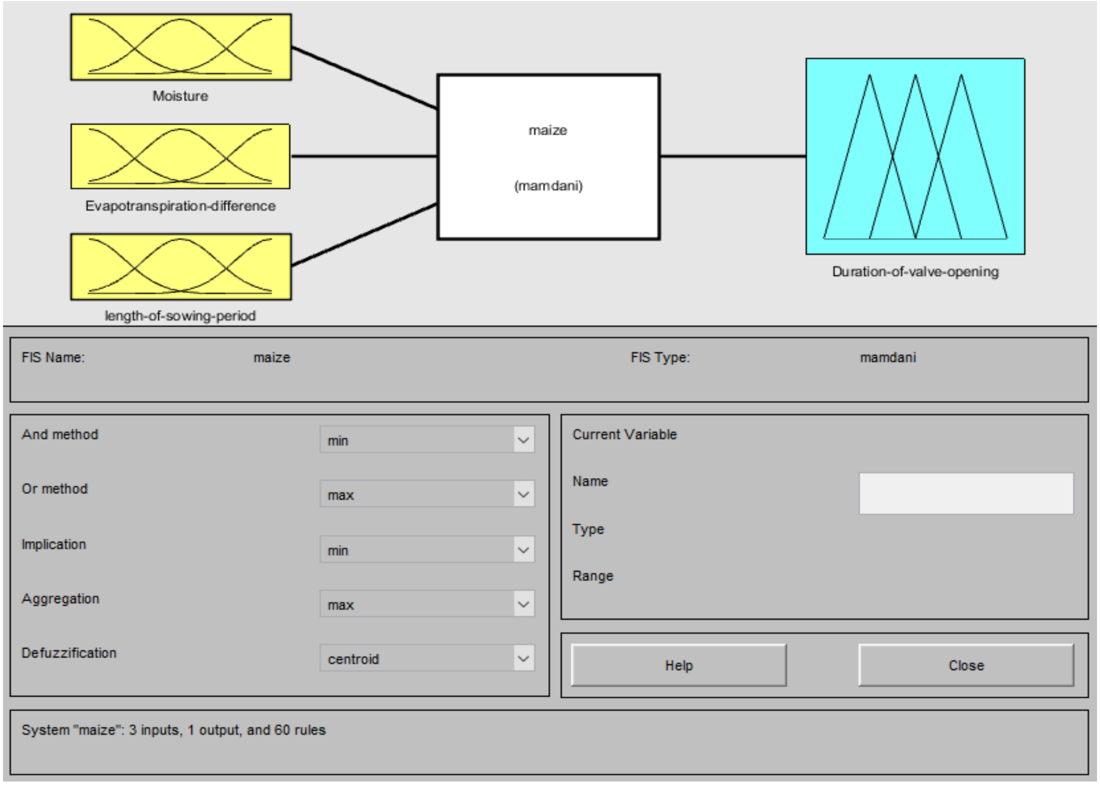

Fig.3.6: The fuzzy logic controller for plant watering system

3.1.5.2. **The Membership Function Editor**

Membership function editor is used to define the shapes of all the membership functions associated with each variable.

The appropriate membership functions shapes and their parameters in a fuzzy system are determined. Fuzziness in a fuzzy set is determined by its membership function. Membership functions may have different shapes like triangular, trapezoidal, Gaussian, etc. The only condition a MF must really satisfy is that it must vary between 0 and 1.

The **Name** field was specified with the name of Membership Function, like dry, medium, wet, large negative, small negative, zero, small positive, large negative, initial stage etc. The **Type** field was specified with the type of Membership Function, like Trimf and Trapmf. The **Parameter** field was specified with the specific range for each Membership Function.

3.1.5.3. Input variable membership functions

The moisture value is one of the input variable membership functions and it has three categories as illustrated in Fig.3.7. The MF has the range of 0 to 100%. And by divide in to three categories denoted by dry, medium and wet. Then the Dry has the range of

0% to 30%, medium has the range of 15% to 65% and wet has the range of 50% to 100%. The type of membership function for the Dry and wet is trapezoidal whereas the membership function for medium is triangular.

Table 3.13: Membership function value for input variable moisture value

Membership Function name	Type of MF	Parameter range
Dry	Trapmf	[-1 0 20 30]
Medium	Trimf	[15 40 65]
Wet	Trapmf	[50 60 100 101]

The evapotranspiration difference input variable has five categories as illustrated in Fig.3.8. The membership functions are denoted by LN, SN, EQ, SP and LP. And the evapotranspiration difference has a range of (-10) to (10) mm/day. The LN category has the range of -10 to -6 mm/day. The SN category has the range of -7 to -1 mm/day, the EQ category has the range of -1.5 to 1.5 mm/day, the SP category has the range of 1 to 7 mm/day and the LP category has the range of 6 to 10 mm/day. The type of membership function for the SN, EQ, and SP is triangular and the membership function for the LN and LP is trapezoidal.

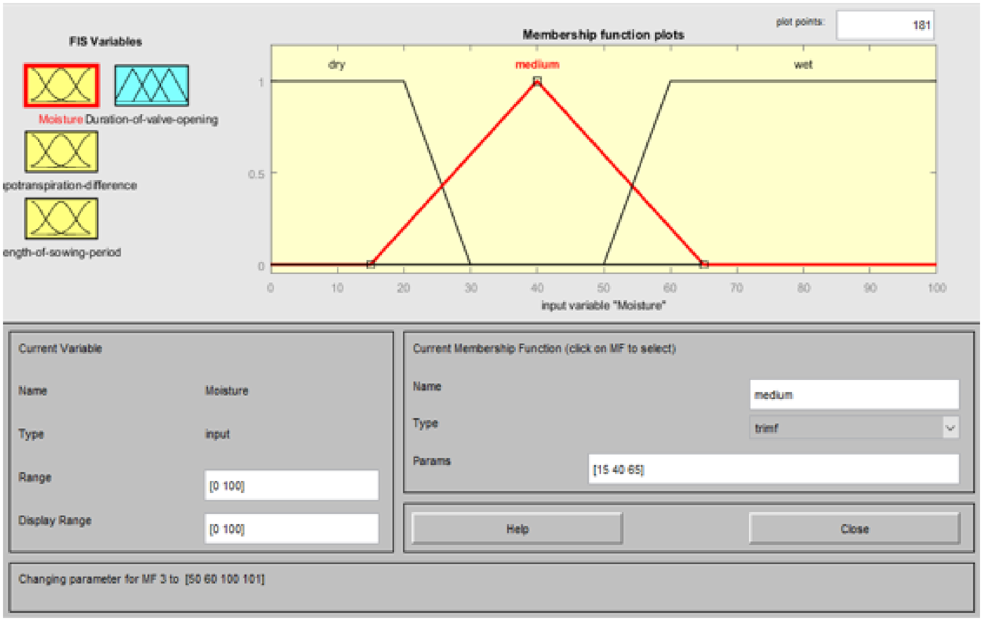

Fig.3.7: The input variable “moisture” MF

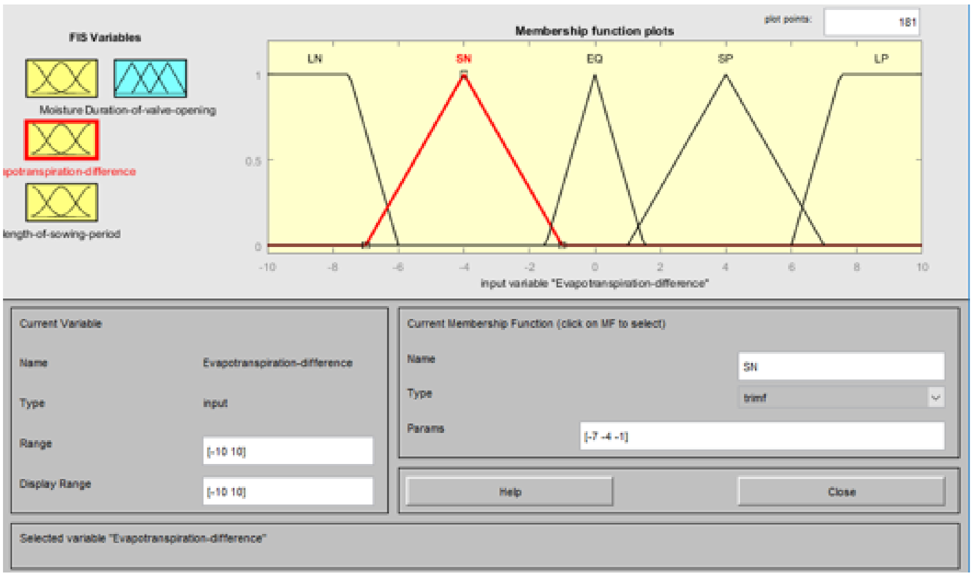

Fig.3.8: The input variable “Evapotranspiration difference” MF

Table 3.14: MF value for input variable evapotranspiration difference

Membership Function name	Type of MF	Parameter range
LN	Trapmf	[-11 -10.5 -7.5 -6]
SN	Trimf	[-7 -4 -1]
EQ	Trimf	[-1.5 0 1.5]
SP	Trimf	[1 4 7]
LP	Trapmf	[6 7.5 10.5 11]

The length of sowing period input variable has four categories as illustrated in Fig.3.9. The membership functions are denoted by initial-stage, dev-stage, mid-stage and late-stage. The sowing period has a range of 0 to140 days. This range was taken from local rain season of maize in the case study area. The initial-stage category has the range of 0 to 20 days, the dev-stage category has the range of 15 to 65 days, the mid-stage category has the range of 40 to 110 days and the late-stage category has the range of 100 to 140 days. The type of membership function for all the initial stage, dev-stage, mid stage and late stage is triangular.

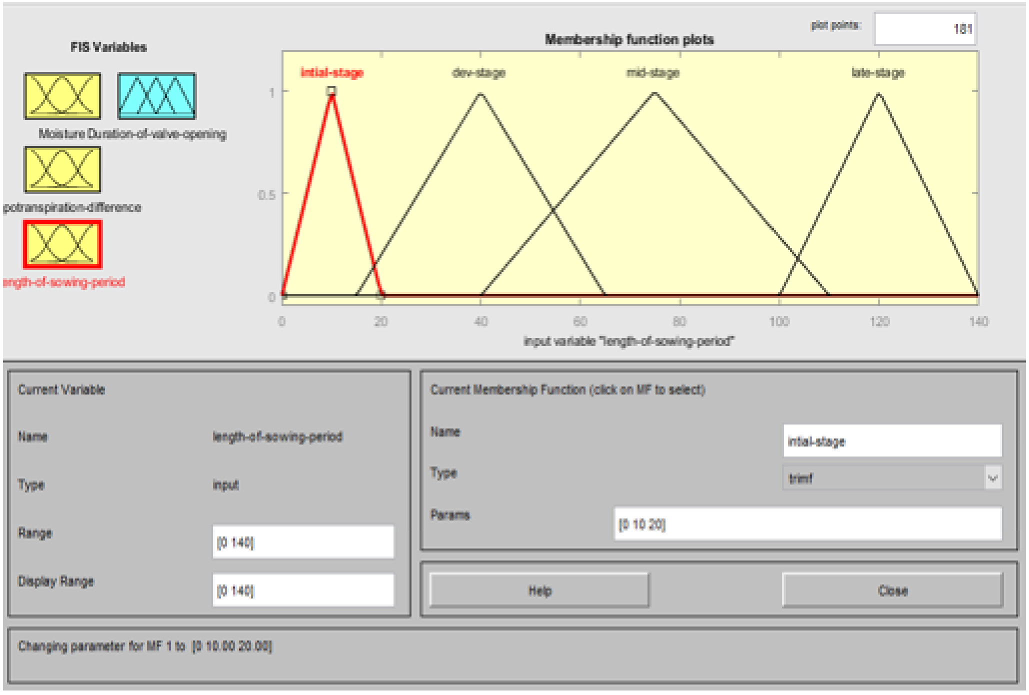

Fig.3.9: The input variable “length of sowing period” MF

Table 3.15: MF value for input variable month after sowing

Membership Function name	Type of MF	Parameter range
Initial-stage	Trimf	[0 10 20]
Dev-stage	Trimf	[15 40 65]
Mid-stage	Trimf	[40 75 110]
Late-stage	Trimf	[100 120 140]

3.1.5.4. Output variable membership functions

The duration of valve opening output variable has five categories as illustrated in Fig.3.10. The membership functions are denoted by zero, v-short, short, long and v-long. For this thesis, the duration of valve opening has a range of 0 to 30 minute. The zero category has the range of 0 to 1 minute. The v-short category has the range of 0.5 to 5.5 minutes. The short category has the range of 3 to 12 minute, the long category has the range of 10 to 20 minute and the v-long category has the range of 18 to 30 minutes. And for all the type of membership function for the zero, v-short, short, long and v-long is triangular.

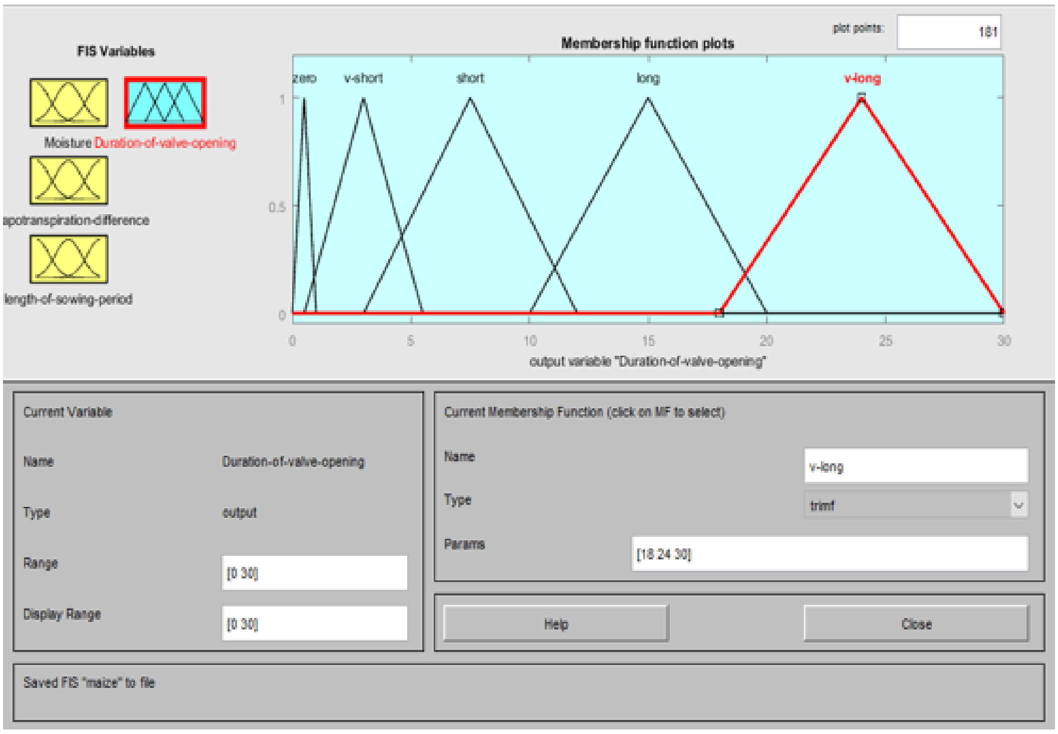

Fig.3.10: The output variable "duration of valve opening" MF

Table 3.16: MF value for output variable duration of valve opening

Membership Function name	Type of MF	Parameter range
Zero	Trimf	[0 0.5 1]
v-short	Trimf	[0.5 3 5.5]
Short	Trimf	[3 7.5 12]
Long	Trimf	[10 15 20]
v-long	Trimf	[18 24 30]

3.1.5.5. Fuzzy Inference System Design

The linguistic fuzzy variables 'large negative (LN)', 'small negative (SN)', 'equal (EQ)', 'small positive(SP)', 'large positive(LP)', 'initial-stage', 'dev-stage', 'mid-stage', 'late-stage', 'dry', 'medium', 'wet' compares the three fuzzy sets; evapotranspiration difference, moisture value and month after sowing. The first input has five fuzzy variables and second input has three fuzzy variables whereas third input has four fuzzy variables, and used to develop Linguistic Rules in Table 3.17 to Table 3.19. The products of these rules are then aligned to determine the duration of valve opening of the actuator. The Table 3.17 to Table 3.19 shows how input linguistic variables derive the output fuzzy sets, which are ‘zero’, ‘v-short’, ‘short’, ‘long’, ‘v-long’.

3.1.5.6. Fuzzy Rules

Rule editor helps to edit the list of rules that defines the behavior of the system. In rule based fuzzy systems, the relationships between variables are represented by means of fuzzy if-then rules for the crop maize 60 rules have been formed for description of fuzzy logic modeling. Since, we have three inputs (moisture value, evapotranspiration difference and month after sowing) for the fuzzy system. And, since each of these three inputs have different fuzzy variables. This moisture value has three fuzzy variables. These are wet, medium and dry. The evapotranspiration difference has five fuzzy variables. It includes LN, SN, EQ, SP and LP and also month after sowing has four fuzzy variables. It also includes initial-stage, dev-stage, mid-stage and late-stage. By simple combination, we can get 60 rules, which have been used, in our system.

Tables 3.17, 3.18 and 3.19 show the fuzzy rule-based system. As an example, some of these rules are given below:

- If (the moisture is dry) and (Evapotranspiration difference is LN) and (length of sowing period is Initial stage) then (duration of Valve opening is **long**)
- If (the moisture is dry) and (Evapotranspiration difference is SN) and (length of sowing period is Initial stage) then (duration of Valve opening is **long**)
- If (the moisture is dry) and (Evapotranspiration difference is EQ) and (length of sowing period is Initial stage) then (duration of Valve opening is **short**)
- If (the moisture is dry) and (Evapotranspiration difference is SP) and (length of sowing period is Initial stage) then (duration of Valve opening is **v-short**)
- If (the moisture is dry) and (Evapotranspiration difference is LP) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
- If (the moisture is dry) and (Evapotranspiration difference is LN) and (length of sowing period is Dev-stage) then (duration of Valve opening is **v-long**)

The remaining rules are listed in the appendix

Table 3.17: Fuzzy input variables and corresponding output when the moisture is dry

When the moisture is **Dry**					
Month after sowing ↓	ETo difference ⟶				
	LN	SN	EQ	SP	LP
Initial stage	Long	Long	Short	v-short	Zero
Dev stage	v-long	v-long	Long	Short	v-short
Mid stage	v-long	v-long	Long	Short	v-short
Late stage	Long	Long	Short	v-short	Zero

Table 3.18: Fuzzy input variables and corresponding output when the moisture is medium

When the moisture is **Medium**					
Month after sowing ↓	ETo difference ⟶				
	LN	SN	EQ	SP	LP
Initial stage	v-short	v-Short	Zero	Zero	Zero
Dev stage	Short	Short	v-Short	Zero	Zero
Mid stage	Short	Short	v-Short	Zero	Zero
Late stage	v-short	v-Short	Zero	Zero	Zero

Table 3.19: Fuzzy input variables and corresponding output when the moisture is wet

When the moisture is **Wet**					
Month after sowing ↓	ETo difference ⟶				
	LN	SN	EQ	SP	LP
Initial stage	Zero	Zero	Zero	Zero	Zero
Dev stage	v-short	Zero	Zero	Zero	Zero
Mid stage	v-short	Zero	Zero	Zero	Zero
Late stage	Zero	Zero	Zero	Zero	Zero

3.1.6. Length of sowing period of crop:

The correct choice of planting time is one of the most important decisions that a crop producer needs to make. It can be critical as far as crop yields and quality achieved are concerned. It can have an important bearing on various costs of production, such as the costs of insect and disease control. Moreover, it determines the season of harvest, and this normally affects prices received for the product.

The climatic requirements of the crop should be matched to the expected conditions applicable to the specific production site selected, if a successful crop is to be produced.

In order for plant growth to take place during favorable conditions, and when aiming to harvest at a specific time, it is essential to know approximately how long it will take the crop to reach market maturity, as well as the length of the cropping season. Obviously, these time spans will vary, depending upon the crop concerned and the cultivar, the cultural practices applied, and the environmental conditions prevailing during growth [24]. In this thesis, the length of the maize cropping season is from June first up to half of November based on the local rain season of case study area. In average, the length of the cropping season of maize is up to 140 days.

3.1.7. Soil moisture

Water contained in soil is called soil moisture. The water is held within the soil pores. Soil water is the major component of the soil in relation to crop growth. If the moisture content of a soil is optimum for crop growth, crops can readily absorb soil water. Not all the water, held in soil, is available to crops. Soil water dissolves salts and makes up the soil solution, which is important as medium for supply of nutrients to growing plants.

Soil moisture sensor measures the soil water and is critical in the whole decision. Outside temperature: To prevent water evaporation, the water planting process will avoid when the outside temperature is high.

Soil moisture sensors measure the volumetric water content in soil. NASA, Retrieved 15 June 2015. Soil moisture is difficult to define because it means different things in different disciplines. For example, a farmer's concept of soil moisture is different from that of a water resource manager or a weather forecaster. Generally, however, soil moisture is the water that is held in the spaces between soil particles. Surface soil moisture is the water that is in the upper 10 cm of soil, whereas root zone soil moisture is the water that is available to plants, which is generally considered to be in the upper 200 cm of soil. Since the direct gravimetric measurement of free soil moisture requires removing, drying, and weighting of a sample, soil moisture sensors measure the volumetric water content indirectly by using some other property of the soil, such as electrical resistance, dielectric constant, or interaction with neutrons, as a proxy for the moisture content. Farmers or gardeners can use portable probe instruments.

Soil moisture sensors typically refer to sensors that estimate volumetric water content.

3.1.8. Valve

This block is controls by the fuzzy logic controller by receiving the signal that is the duration of the valve opening time. Variable valve timing (VVT) systems is used. This system refer to valve actuation systems that are able to change the duration of the valve timing [25].

The electromechanical system that has been developed is able to continuously and independently vary the valve duration based on operating conditions available to the controller. Solenoid valves are electromechanical valves that are controlled by stopping or running an electrical current through a solenoid, in order to change the state of the valve. A solenoid is a coil of wire that is magnetized when electricity runs through it.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. RESULTS

As discussed in chapter three, we have three input parameters for fuzzy logic controller. By combining two of these three input parameters alternatively, we can obtain three different surface plot of duration valve opening (moisture value with month after sowing, evapotranspiration difference with month after sowing and moisture value with evapotranspiration difference) as shown below.

Based on the fuzzy rule, a surface plot of Duration of valve opening fuzzy prediction can be obtained, as shown in Fig.4.1. It shows that the duration of valve opening is gradually increased with the decreasing of Moisture value and mid-season of the crop sowing period. In this figure, the duration of the valve opening is highly increased in middle season that is between 20 days and 100 days after sowing and in the dry moisture that is below 35%. In this case, the duration of valve opening is high.

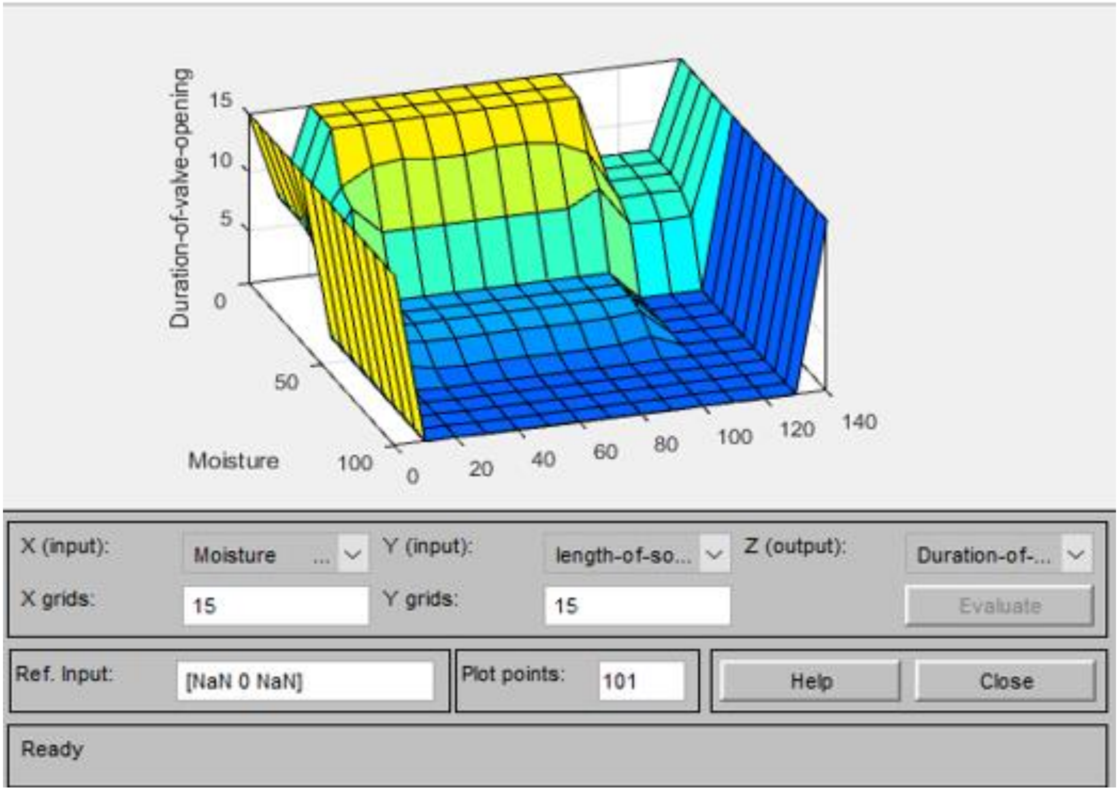

Fig. 4.1: Surface view of Moisture value and crop sowing period

When we combine month after sowing with evapotranspiration difference, a surface plot of Duration of valve opening fuzzy prediction can be obtained, as shown in Fig.4.2.

It shows that the duration of valve opening is gradually increased with the decreasing of evapotranspiration difference and mid-season of the crop sowing period. In this figure the duration of the valve opening is highly increased in middle season that is between 20 days and 100 days after sowing and below the -2 (SN) of evapotranspiration difference. In this case, also the duration of valve opening is high.

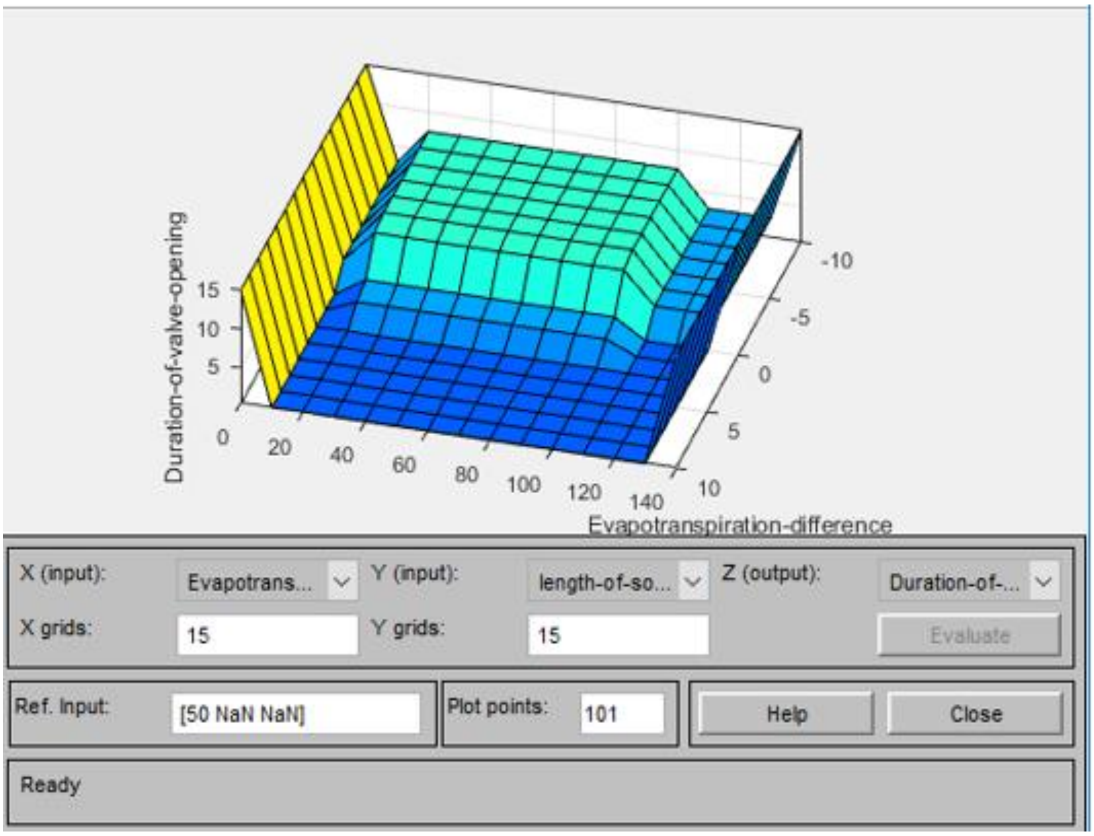

Fig. 4.2: Surface view of ETo difference and sowing period

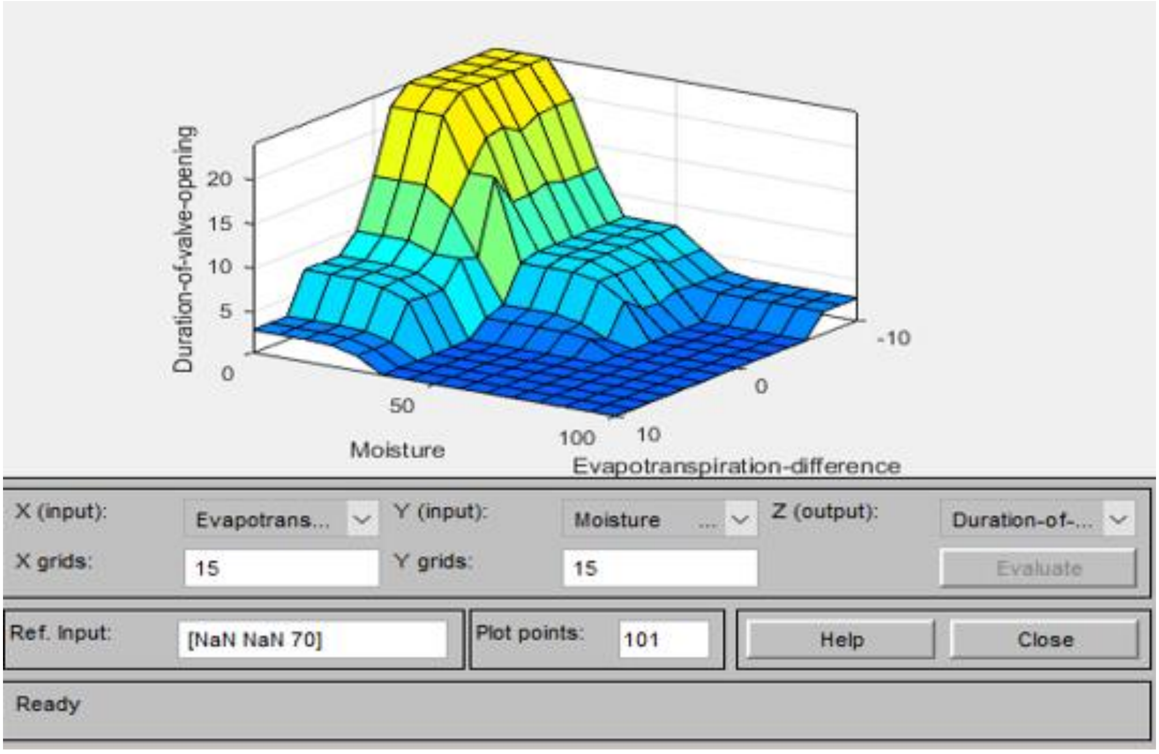

Fig. 4.3: Surface view ETo difference and moisture value

Based on the fuzzy rule, a surface plot of Duration of valve opening fuzzy prediction can be obtained, as shown in Fig.4.3. It shows that the duration of valve opening is gradually increase with the decreasing of Moisture value and with the decreasing of evapotranspiration difference. In this figure the duration of the valve opening is highly increased below the -2 (SN) of evapotranspiration difference and in the dry moisture that is below 35%. In this case, the duration of valve opening is high.

As illustrated in Fig.4.4, the values of 50% (the moisture is medium), 0 (the evapotranspiration is zero) and 70 days (the month after sowing is mid stage) have been applied to the input variables of moisture, evapotranspiration difference and month after sowing respectively. The corresponding crisp output of the fuzzy logic on the duration of valve opening is 7.52 minute.

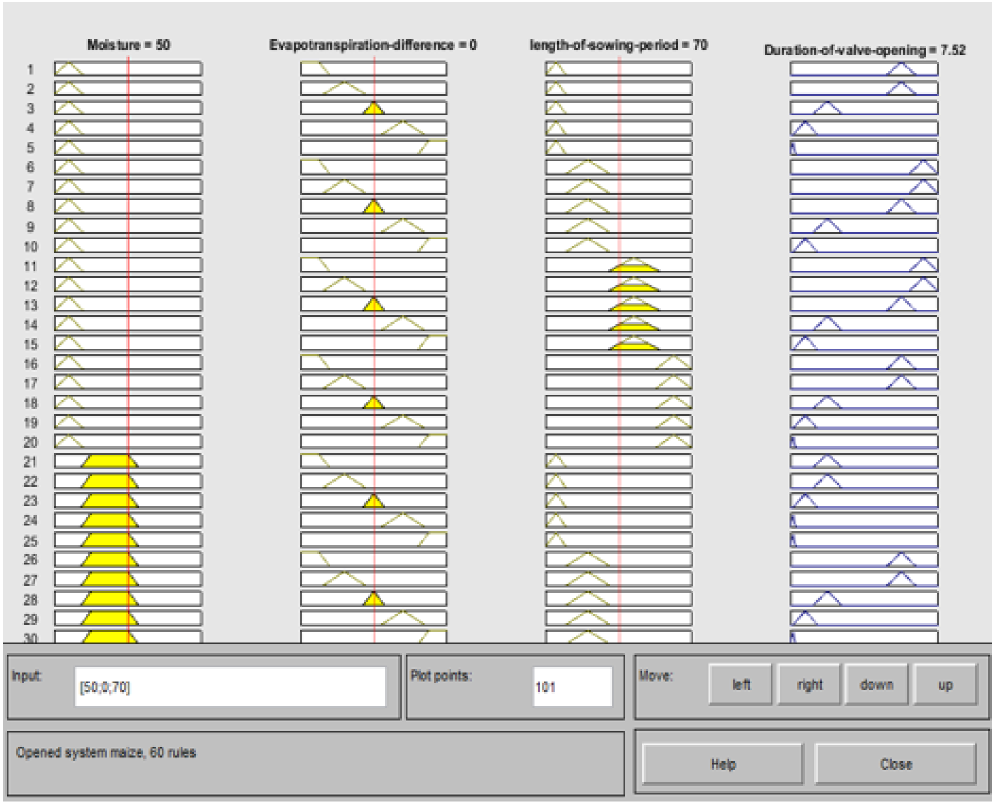

Fig. 4.4: Rule view of fuzzy design plant watering system

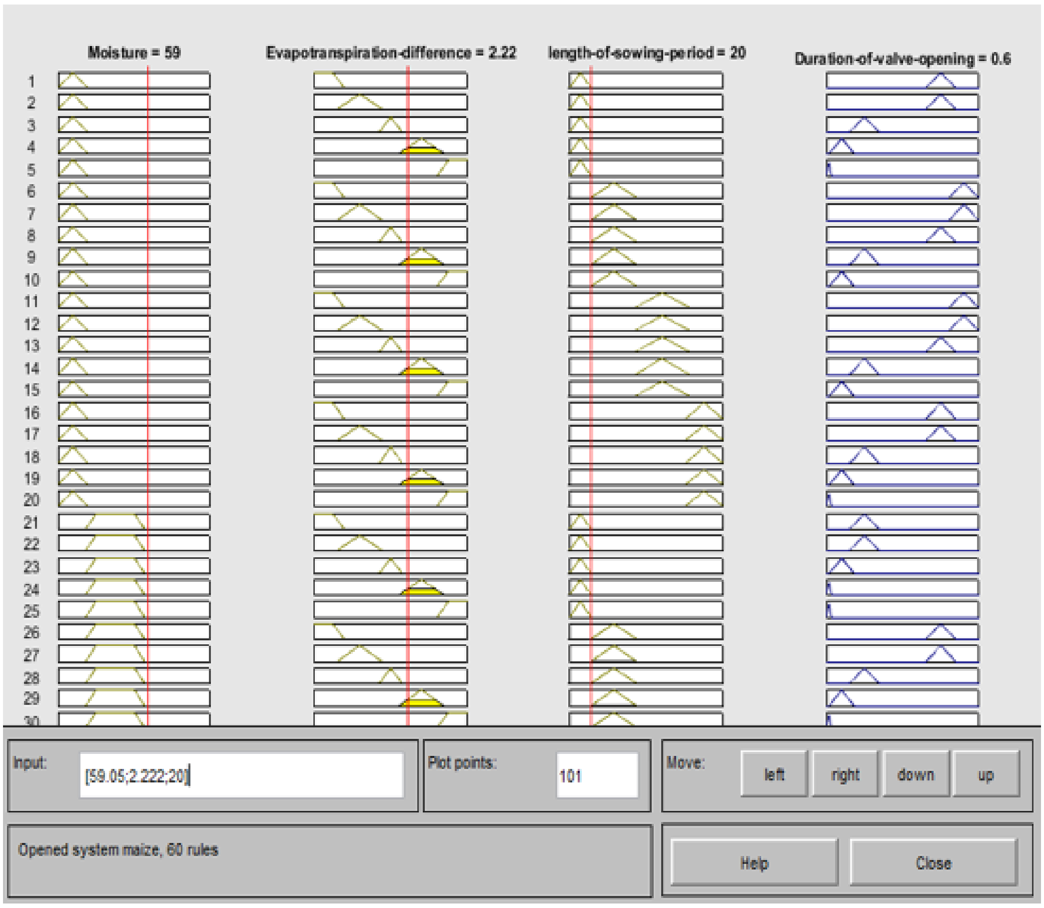

Fig. 4.5: Rule view of fuzzy design plant watering system

As illustrated in Fig.4.5, the values of 59% (the moisture is wet), 2.22 (the evapotranspiration difference is small positive SP) and 20 days (the month after sowing is initial stage) have been applied to the input variables of moisture, evapotranspiration difference and month after sowing respectively. The corresponding crisp output of the fuzzy logic on the duration of valve opening is 0.6 minute.

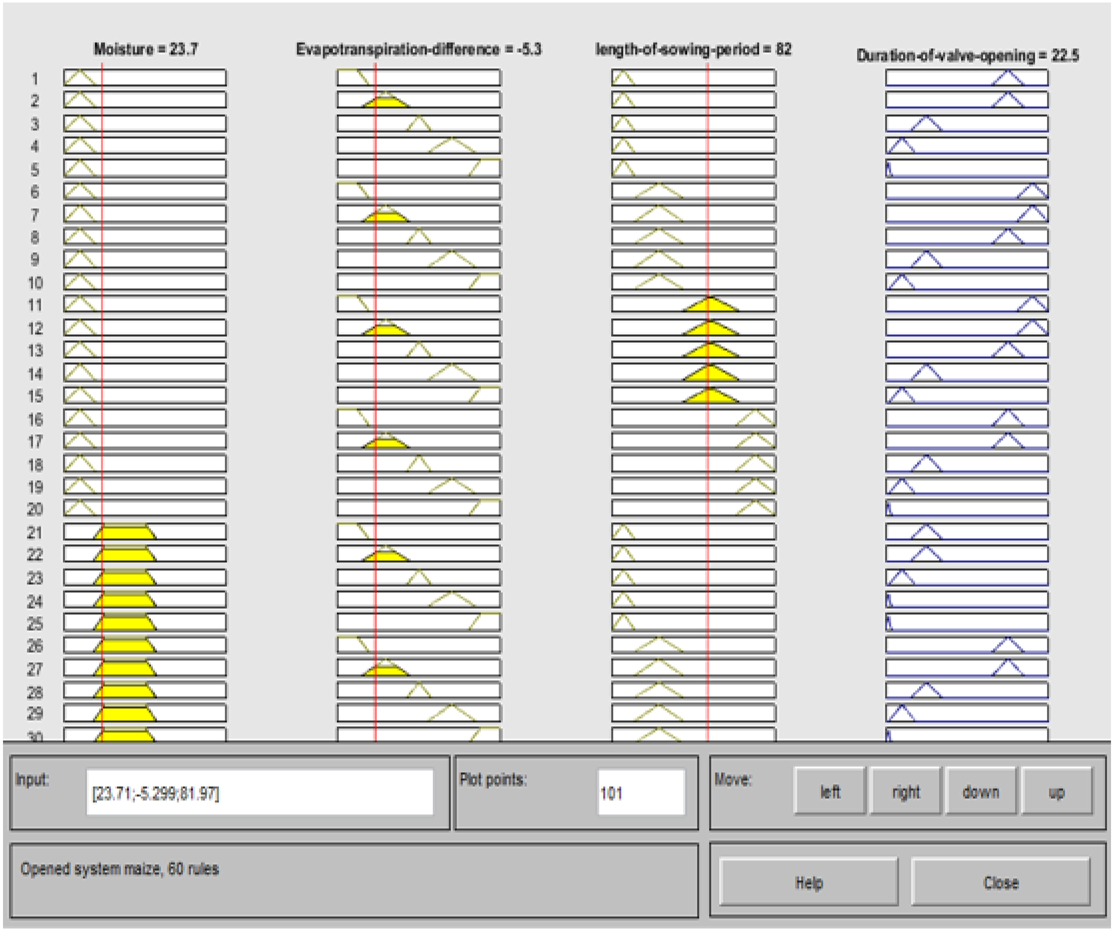

Fig. 4.6: Rule view of fuzzy design plant watering system

As illustrated in Fig.4.6, the values of 23.7% (the moisture is dry), (-5.3) (the evapotranspiration difference is large negative LN), and 82 days (the month after sowing is mid stage) have been applied to the input variables of moisture, evapotranspiration difference and month after sowing respectively. The corresponding crisp output of the fuzzy logic on the valve is 22.5 minute.

Generally, when the evapotranspiration difference is highly negative, the moisture value of the soil is dry and the month after sowing of the crop is in mid stage the duration of valve opening was very long. And when the evapotranspiration difference is highly positive, the moisture value of the soil is wet and the month after sowing of the crop is in initial stage and late stage the duration of valve opening was zero or very short.

4.2. Discussion

This chapter discusses the designed system and its output, evapotranspiration estimation, desired evapotranspiration and difference of evapotranspiration. And also it discusses the designed automatic plant watering system and output displays of duration of valve opening.

The Evapotranspiration estimation value is compared with the desired evapotranspiration value and the error value (evapotranspiration difference) used as the one input of the fuzzy logic controller, in order to control the duration of valve opening.

In the fuzzy controller design, we have three basic inputs

- ✓ Evapotranspiration difference)
- ✓ Moisture value and
- ✓ Month after sowing

The ranges for these input parameters are given in chapter three.

Evapotranspiration: to calculate the evapotranspiration difference, we need to know the evapotranspiration calculation, which is dependent on four variable parameters. These are:

- ✓ Humidity measurement
- ✓ Temperature measurement
- ✓ Radiation measurement and
- ✓ Wind speed measurement

Depending on different values of each of these four parameters, we get different value for evapotranspiration calculation and consequently which enables us obtain different values for evapotranspiration difference. For example, we have demonstrated in Fig.4.7, Fig.4.9 and Fig.4.11 as follows.

Exemplary explanation for Calculation of evapotranspiration input value

In the following part, we will consider three cases in which we do different analysis based on different input parameters of evapotranspiration estimation. And extract one of the three inputs of fuzzy controller to be designed values. We should notice that fuzzy logic controller has three inputs (moisture measurement, evapotranspiration difference and month after sowing) and in the following discussions, we have obtained for one of the three inputs (that is only for the evapotranspiration node input) for three different cases as follows. And, we have generated three different figures correspondingly.

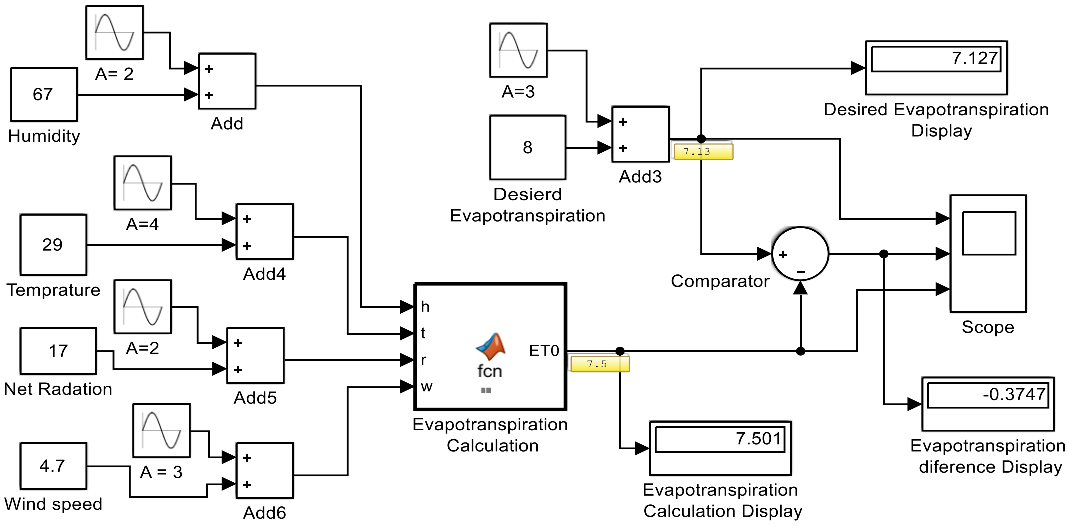

Fig. 4.7: Evapotranspiration difference simulink diagram

Case 1: Based on the input values of the evapotranspiration estimation of Fig.4.7, the evapotranspiration difference is nearly zero -0.3747 (zero). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation. The desired reference evapotranspiration value is 7.13 at 100 running time. The evapotranspiration estimation is calculated by setting 67% for humidity measurement value, 29^{o}C for temperature measurement, 17% for radiation and 4.7 mph for wind speed by using Penman–Monteith equation. The evapotranspiration estimation obtained for this setup is 7.5 mm/day in June 2015 at Assosa. In this case, the desired evapotranspiration and the evapotranspiration estimation are nearly equal. Fig.4.8 shows the output display of this value. From this figure, the blue color waveform indicates the evapotranspiration calculation (estimation) whereas the yellow and red color indicates the desired evapotranspiration and the evapotranspiration difference respectively. From this figure, the red color signal is sent to one of the inputs of the fuzzy logic controller.

h,t,r,w and ET0 are defined in the appendix C. This definition goes to for every simulink diagrams in the document.

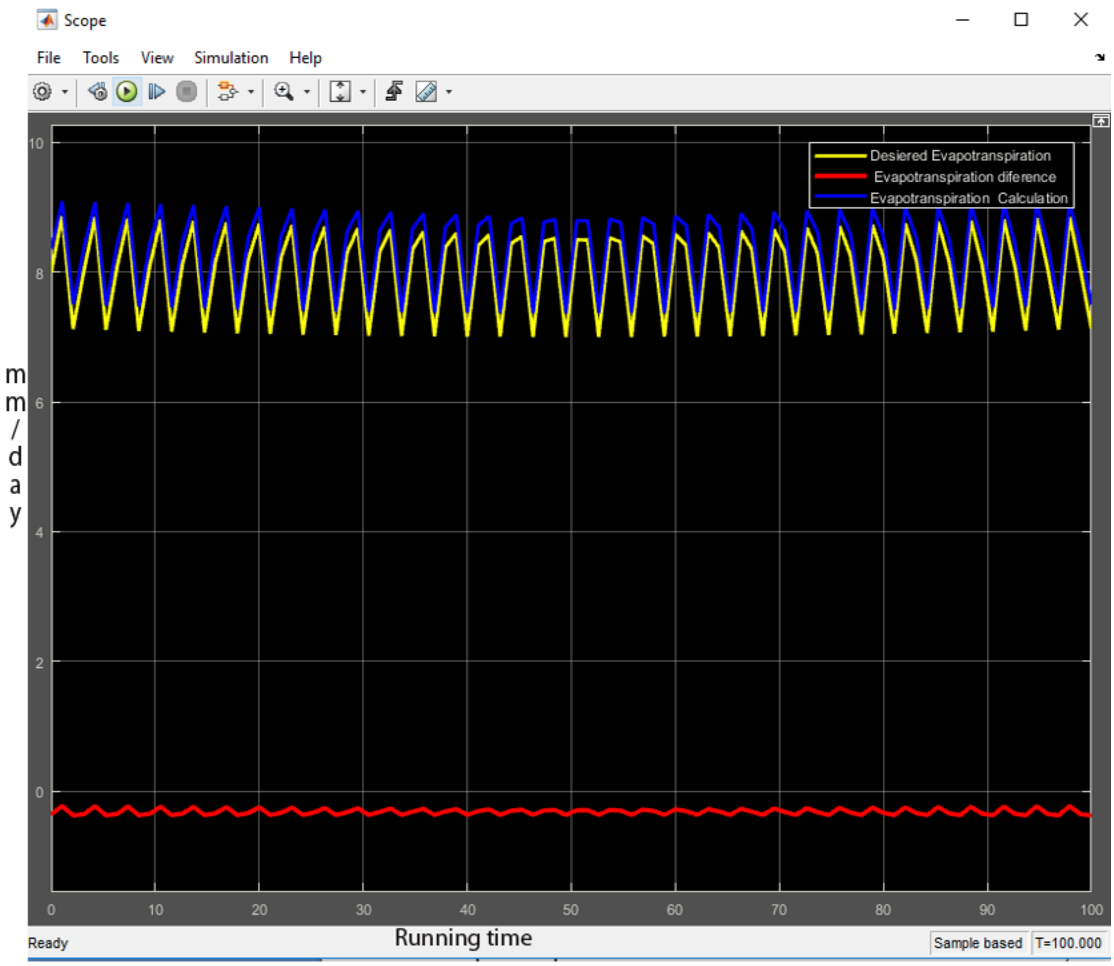

Fig. 4.8: Evapotranspiration difference output display

Case 2: Based on the input values of the evapotranspiration estimation of Fig.4.9, the evapotranspiration difference is 1.71 (small positive (SP)). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation. The desired reference evapotranspiration value is 7.13 mm/day at 100 running time. The evapotranspiration estimation is calculated by setting 72% for humidity measurement value, 27^{o}C for temperature measurement, 12% for radiation and 4.3 mph for wind speed by using Penman–Monteith equation. The evapotranspiration estimation obtained for this setup is 5.4 mm/day in July 2017 at Assosa as shown in Fig.4.9. In this case, the desired reference evapotranspiration is greater than the evapotranspiration estimation. Fig.4.10 shows the output display of this value. From this figure, the blue color waveform indicates the evapotranspiration calculation (estimation) whereas the yellow and red color indicate the desired evapotranspiration and the evapotranspiration difference respectively. From this figure, the red color signal is sent to one the inputs of the fuzzy logic controller.

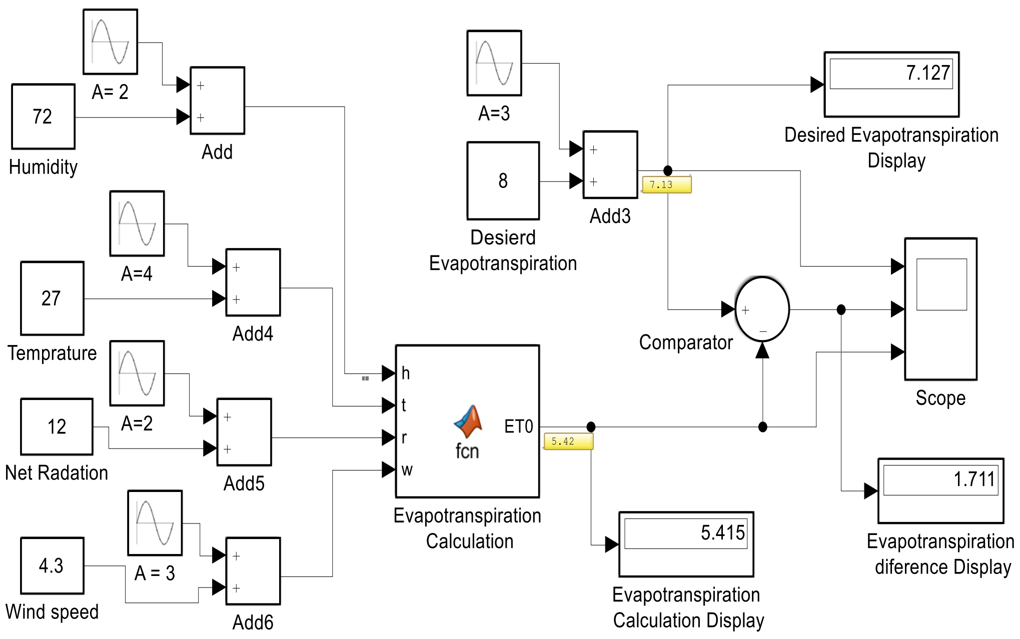

Fig. 4.9: Evapotranspiration difference simulink diagram

Case 3: And also based on the input values of the evapotranspiration estimation of Fig.4.11, the evapotranspiration difference is -3.857 (small negative SN). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation. The desired reference evapotranspiration value is 7.13 mm/day. The evapotranspiration estimation is calculated by setting 57% for humidity measurement value, 31^{o}C for temperature measurement, 28% for radiation and 4.5 mph for wind speed by using Penman–Monteith equation. The evapotranspiration estimation obtained for this setup is 10.64 mm/day in June 2017 at Assosa. In this case, the desired reference evapotranspiration is less than the reference evapotranspiration estimation. Fig.4.11 shows the output display of this value. From Fig.4.12 the blue color, waveform indicates the evapotranspiration calculation (estimation) whereas the yellow and red color indicates the desired evapotranspiration and the evapotranspiration difference respectively. Also from this figure, the red color signal is sent to one of the inputs of the fuzzy logic controller.

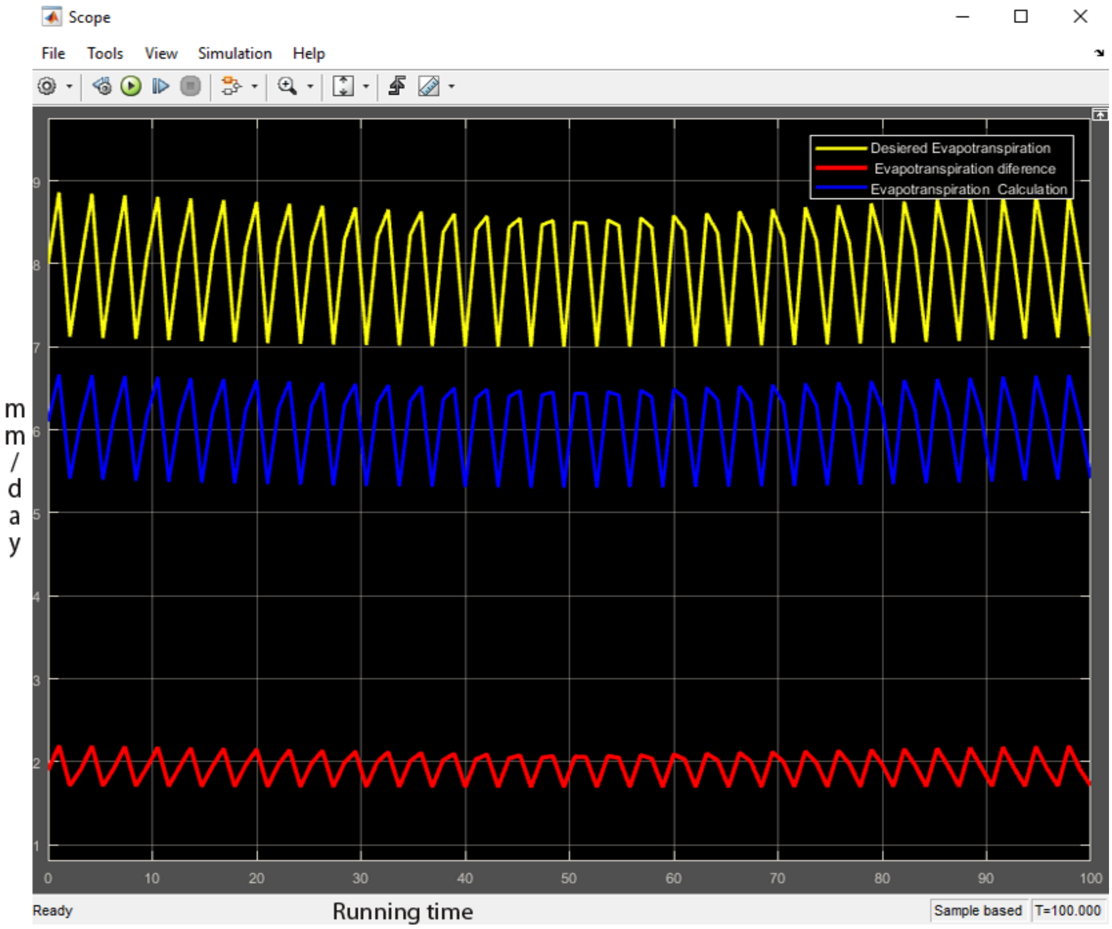

Fig. 4.10: Evapotranspiration difference output display

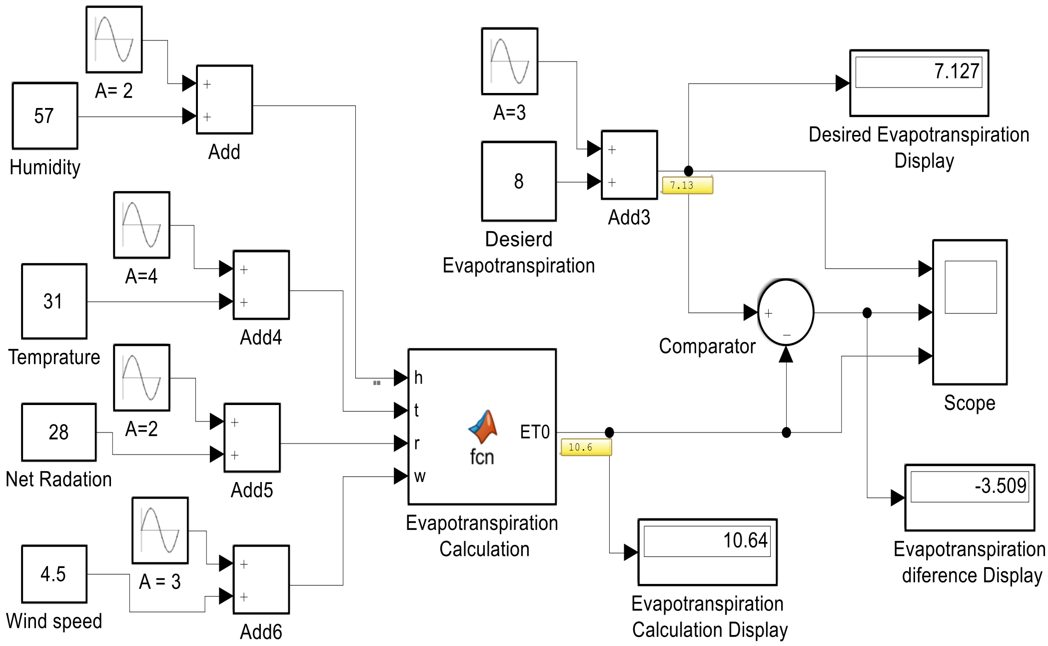

Fig. 4.11: Evapotranspiration difference simulink diagram

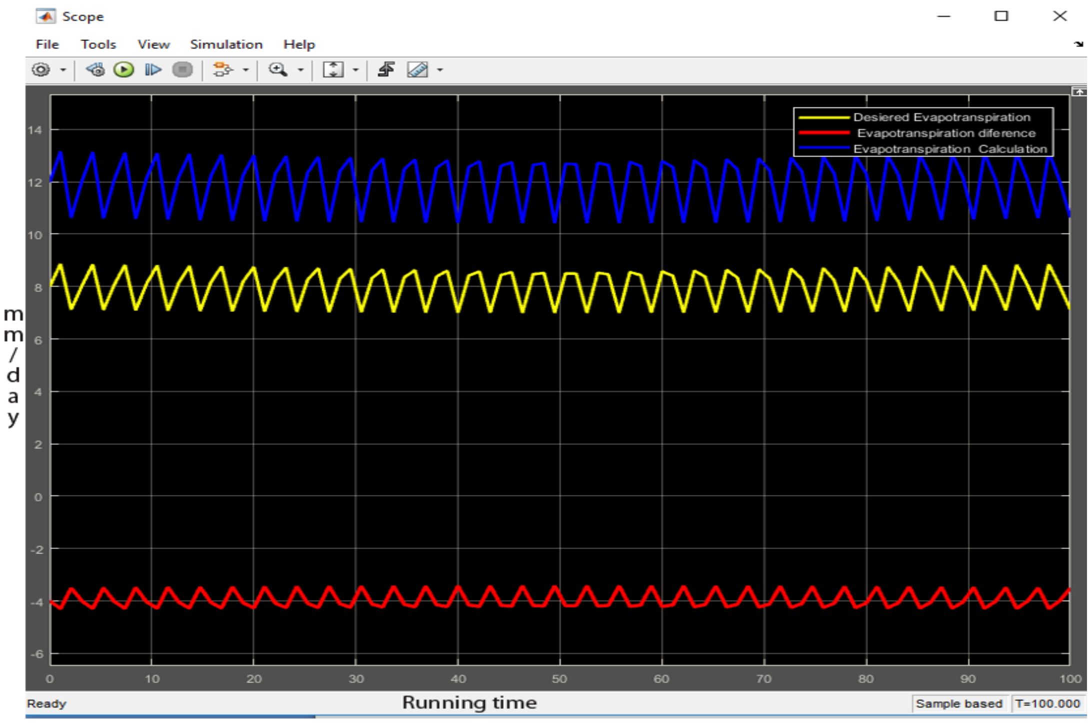

Fig. 4.12: Evapotranspiration difference output display

As we have seen for each three cases, we have obtained three values (-3.857 (small negative SN), -0.3747 (zero) and 1.719 (small positive SP)) for the evapotranspiration difference input node of the fuzzy logic controller. And we use these three inputs (-3.857, -0.3747 and 1.719) independently with other two inputs (moisture value and month after sowing).

As explained in the first part of this topic the three variables are dependent on different cord and can have different values. And having seen how the evapotranspiration difference is calculated, now we will consider and analyze the fuzzy logic controller system by applying all the three input variables that is evapotranspiration difference, moisture value and month after sowing as follows.

We will show the following analysis based on the different values of the mentioned inputs.

Based on the Case 1 above, the evapotranspiration difference has been calculated and it used as one of the inputs for fuzzy logic controller. This evapotranspiration difference value -0.3747, the moisture value 50% and the month after sowing of 60 days are inputs for fuzzy logic controller. The output value of fuzzy logic controller is 7.084 minute (short) at 100 running time display. In this case, the valve is open for nearly seven minutes.

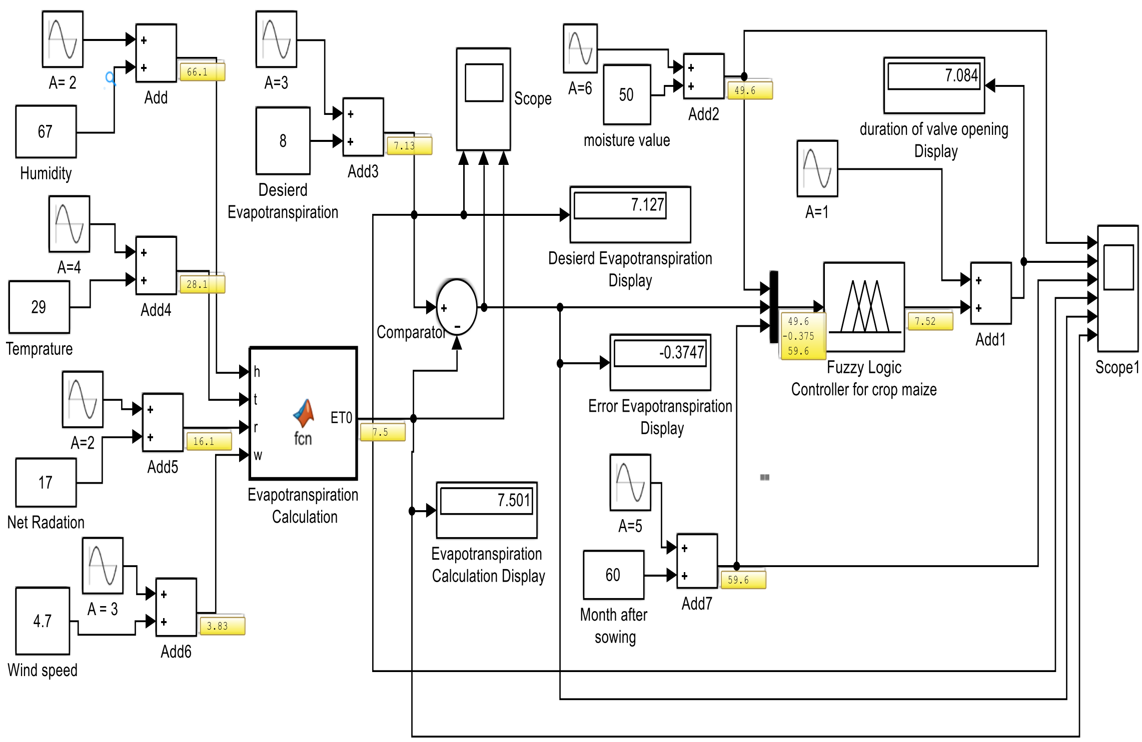

Fig. 4.13: Matlab simulink diagram of automatic plant watering system

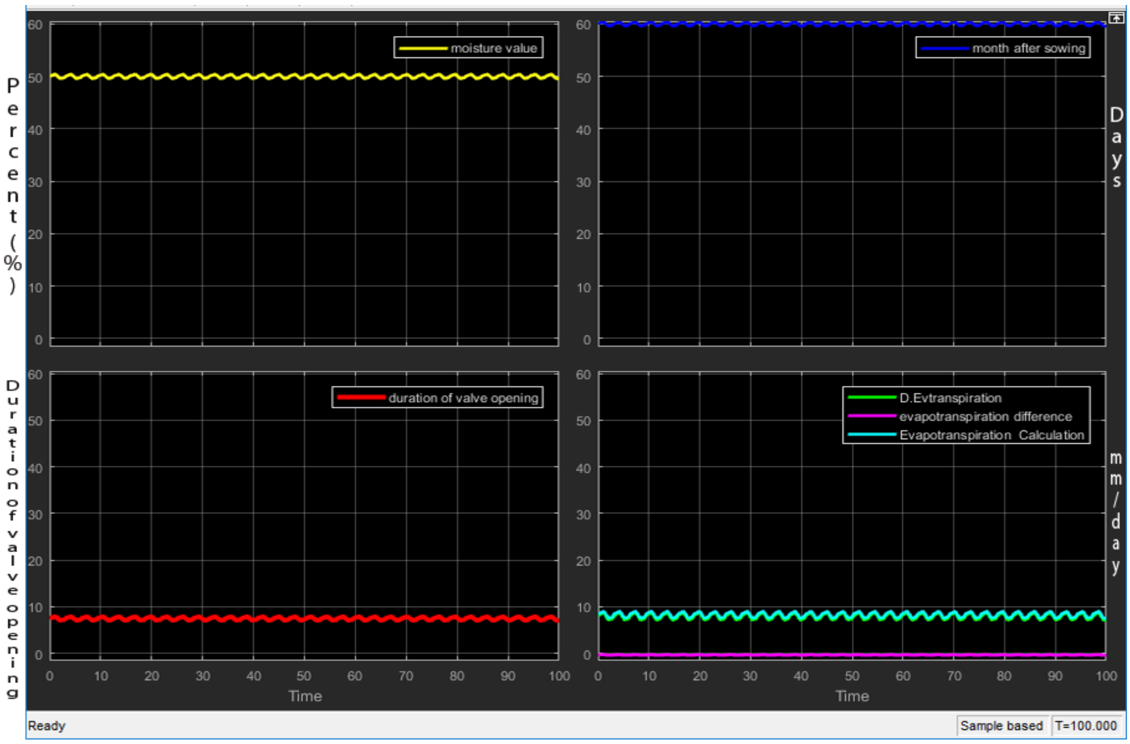

Fig. 4.14: Matlab simulink output of automatic plant watering system

Secondly, based on the input values of the evapotranspiration estimation of Fig.4.15, the evapotranspiration difference is -8.173 (large negative LN). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation. The desired reference evapotranspiration value is 7.13

mm/day at 100 running time. The evapotranspiration estimation is calculated by setting 31% for humidity measurement value, 31°C for temperature measurement, 39% for radiation and 3.8 mph for wind speed by using Penman–Monteith equation. The evapotranspiration estimation obtained for this setup is 15.3 in November 2017 at Assosa. In this case, the desired reference evapotranspiration is less than the reference evapotranspiration estimation. The evapotranspiration difference value -8.173 (large negative LN), moisture value 50 % (medium) and the month after sowing 60 days (dev-stage) are inputs for fuzzy logic controller. The output value of fuzzy logic controller is 22.5 minute (v-long) at 100 running time display.

Thirdly, based on the input values of the evapotranspiration estimation of Fig.4.17, the evapotranspiration difference is 1.71 (small positive SP). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation, as explained above in case 2. The evapotranspiration difference value 1.71 mm/day (small positive SP), the moisture value 50% (medium) and the month after sowing 60 days (mid-stage) are inputs for fuzzy logic controller. The output value of fuzzy logic controller is 2.56 minute (very short) at 100 running time display.

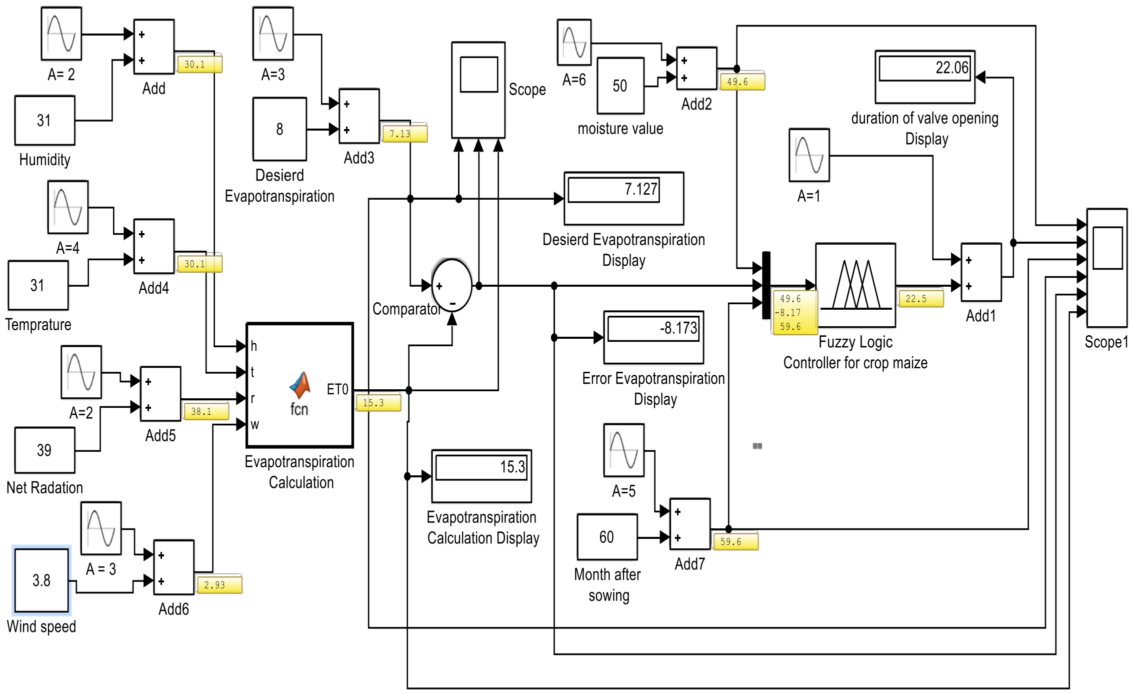

Fig. 4.15: Matlab simulink diagram of automatic plant watering system

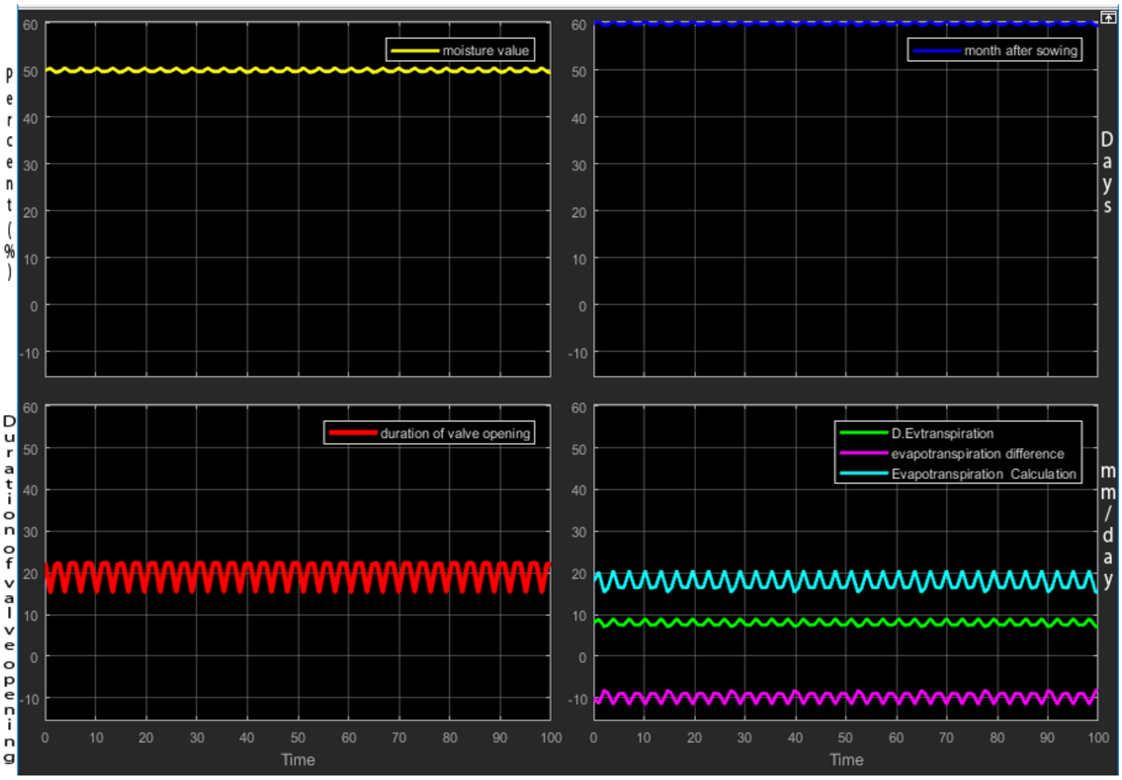

Fig. 4.16: Matlab simulink output of automatic plant watering system

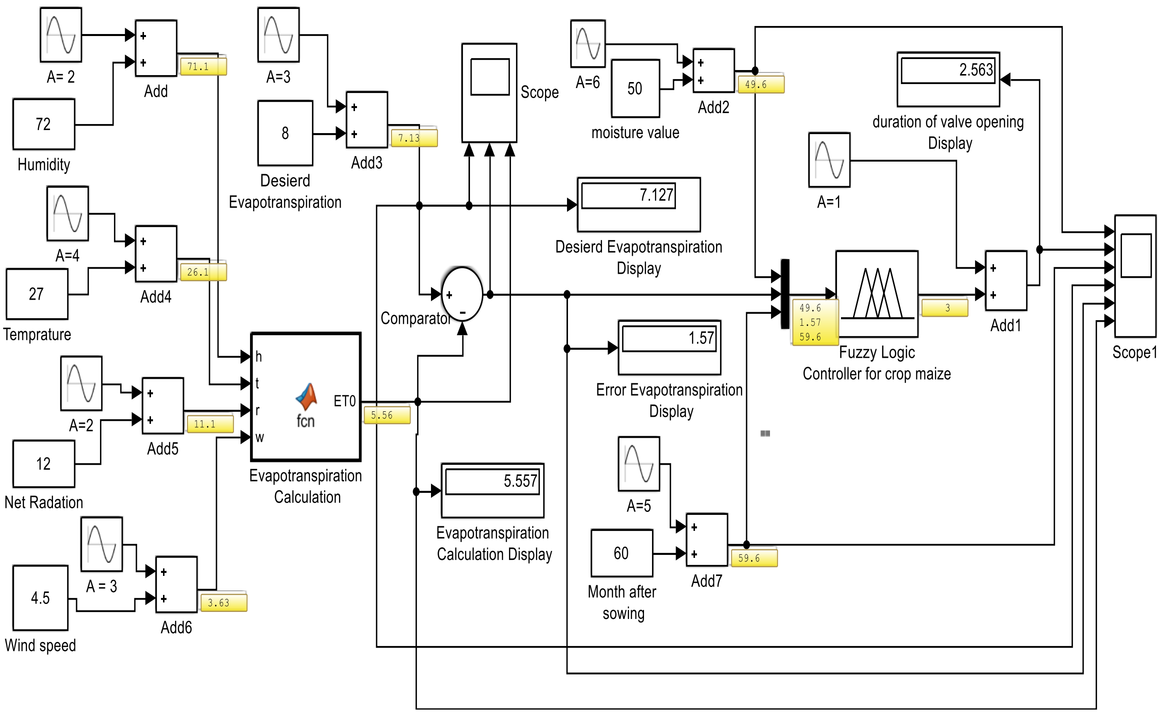

Fig. 4.17: Matlab simulink diagram of automatic plant watering system

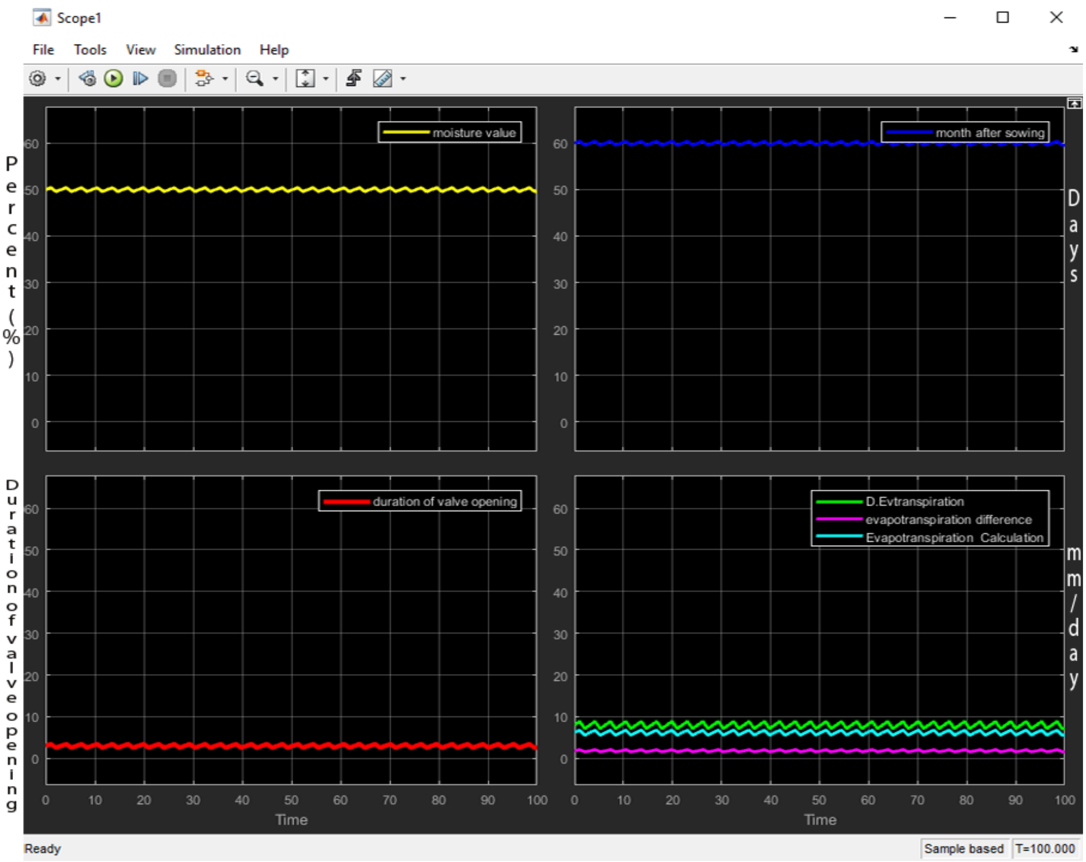

Fig. 4.18: Matlab simulink output of automatic plant watering system

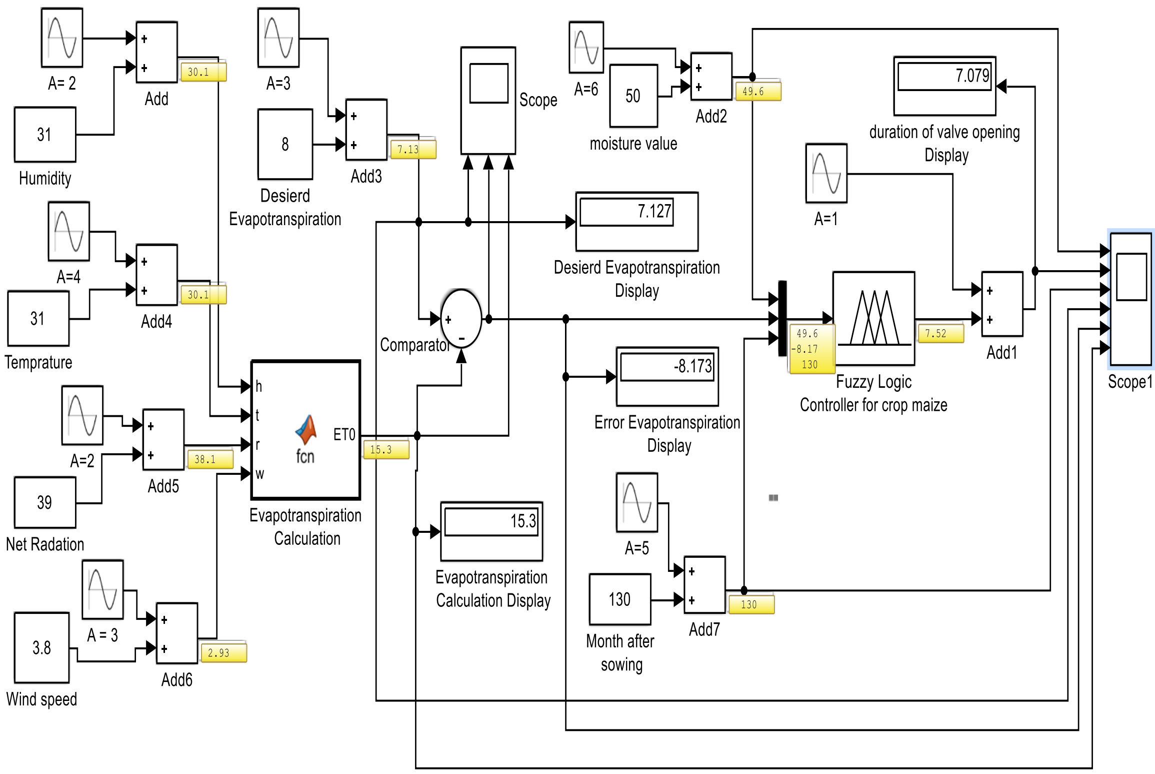

Fig. 4.19: Matlab simulink diagram of automatic plant watering system

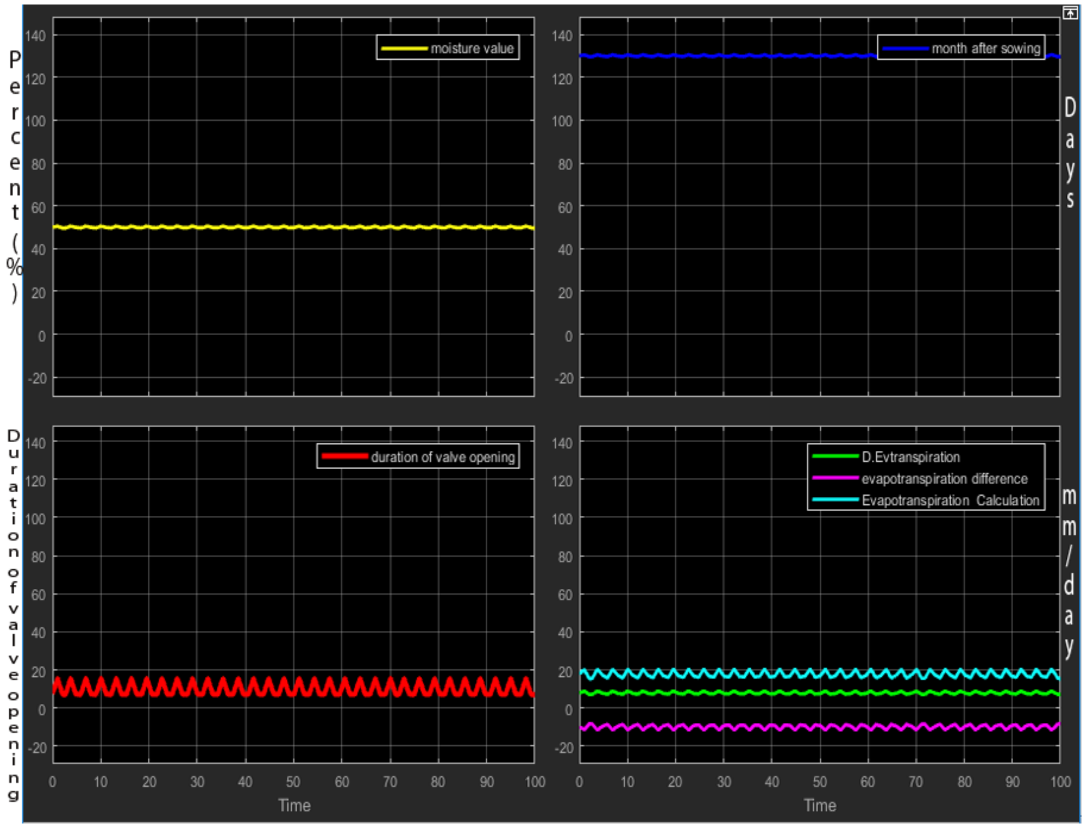

Fig. 4.20: Matlab simulink output of automatic plant watering system

Fourthly, based on the input values of the evapotranspiration estimation of Fig.4.19, the evapotranspiration difference is -8.173 (large negative LN). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation. The desired reference evapotranspiration value is 7.13 at 100 running time. The evapotranspiration estimation is calculated by setting 31% for humidity measurement value, 31°C for temperature measurement, 39% for radiation and 3.8 mph for wind speed by using Penman–Monteith equation. The evapotranspiration estimation obtained for this setup is 15.3 mm/day in November 2017 at Assosa. In this case, the desired reference evapotranspiration is less than the reference evapotranspiration estimation. The evapotranspiration difference value -8.173 (large negative LN), moisture value 50% (medium) and the month after sowing is 130 days (late-stage) are inputs for fuzzy logic controller. The output value of fuzzy logic controller is 7.5 minute (short) at 100 running time display.

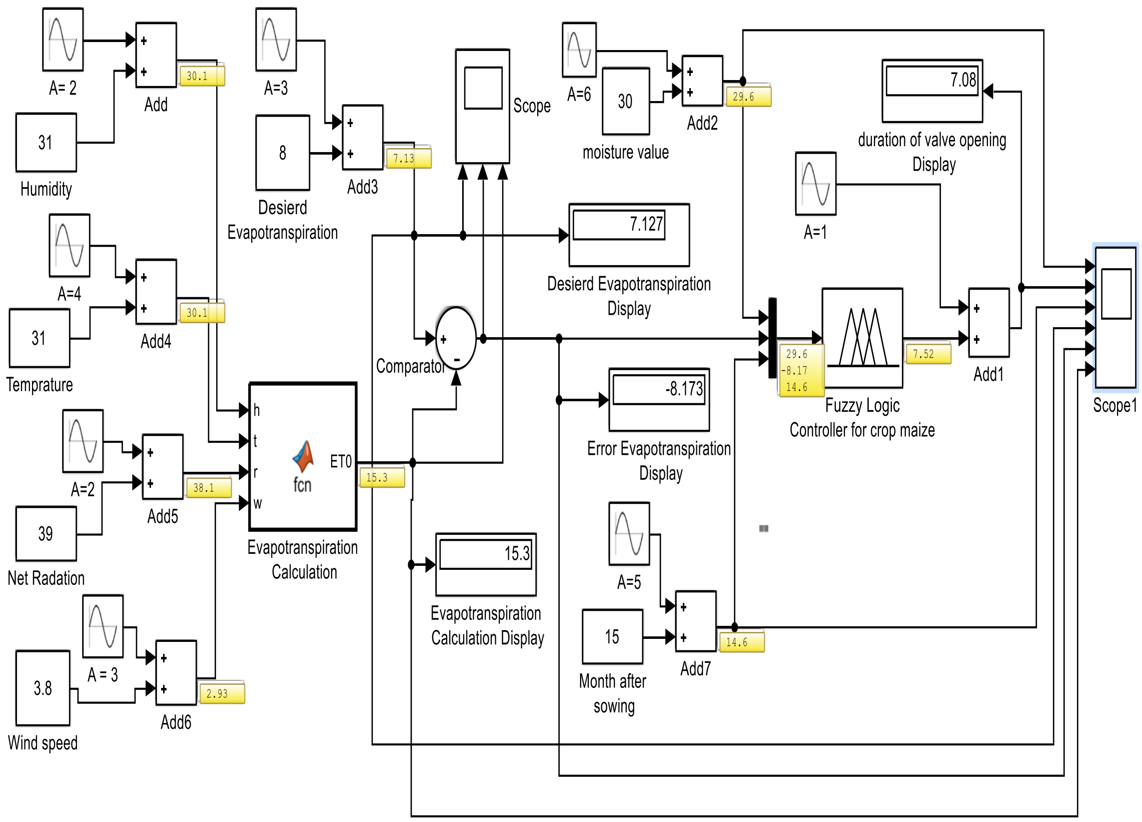

Fig. 4.21: Matlab simulink diagram of automatic plant watering system

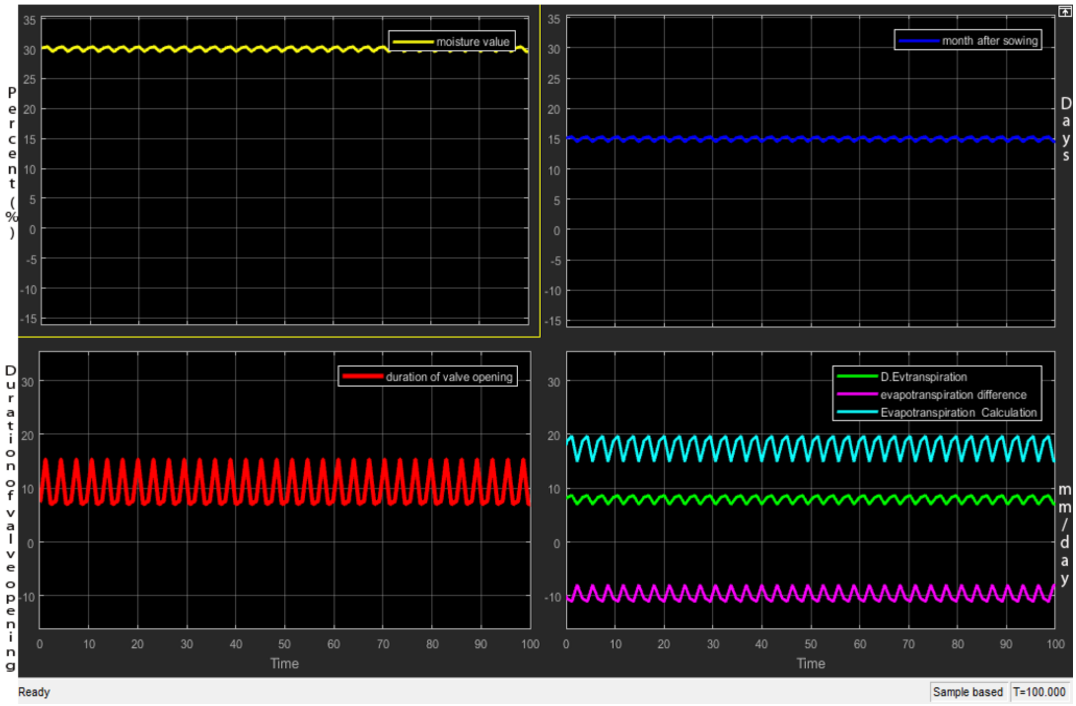

Fig. 4.22: Matlab simulink output of automatic plant watering system

Fifthly, based on the input values of the evapotranspiration estimation of Fig.4.21, the evapotranspiration difference is (-8.173). This result is obtained from the difference between the desired reference evapotranspiration and the evapotranspiration estimation. The desired reference evapotranspiration value added with the sine function is 7.13 at 100 running time. The evapotranspiration estimation is calculated by setting 31% for humidity measurement value, 31^{o}C for temperature measurement, 39% for radiation and 3.8 mph for wind speed by using Penman–Monteith equation. The evapotranspiration estimation obtained for this setup is 15.3 mm/day in November 2017 at Assosa. In this case the desired reference evapotranspiration is less than the reference evapotranspiration estimation. the evapotranspiration difference -8.173 (large negative LN), the moisture value 30% (dry) and the month after sowing 15 days (initial-stage) are inputs for fuzzy logic controller. The output value of fuzzy logic controller is 7 minute (short) at 100 running time display.

Fig.4.14, Fig.4.16, Fig.4.18, Fig.4.20, Fig. 4.22 have been shown, the output displays of matlab simulink diagram of automatic plant watering system at different input values. From these figures, the blue color waveform indicates the month after sowing, the yellow color waveform indicates the moisture value, the pink color waveform indicates the evapotranspiration difference, the green color waveform indicates the desired evapotranspiration, the cyan color waveform indicates the evapotranspiration calculation (estimation) whereas the red color indicates the duration of valve opening time.

From the simulation of automatic plant watering system figures as shown above the horizontal axis is the simulation (running) time. The vertical axis is vary based on the input parameters and output parameter. The vertical axis for the input parameter moisture value is percent (%), month after sowing is days, duration of valve opening is minute and the vertical axis for desired evapotranspiration, evapotranspiration estimation (calculation) and evapotranspiration difference is mm/day.

The table below summarized the above discussion.

Table 4.1: Examples of input and output value at different values

				Input values for Fuzzy			Output value
		ETo	Desired ET	ET difference	Moisture value	Month after sowing	Duration of valve opening
Humidity	67%	7.5 mm/day	7.15 mm/day	-0.374 mm/day	50 %	60 days	7.84 minute
Temperature	29 ^oC						
Radiation	17%						
Wind speed	4.7 mph						
Humidity	31%	15.3 mm/day	7.15 mm/day	-8.173 mm/day	50%	60 days	22.5 minute
Temperature	31 ^oC						
Radiation	39 %						
Wind speed	3.8 mph						
Humidity	72%	5.4 mm/day	7.15 mm/day	1.71 mm/day	50%	60 days	2.56 minute
Temperature	27 ^oC						
Radiation	12%						
Wind speed	4.3 mph						
Humidity	31%	15.3 mm/day	7.15 mm/day	-8.173 mm/day	50%	130 days	7.5 minute
Temperature	31 ^oC						
Radiation	39 %						
Wind speed	3.8 mph						
Humidity	31%	15.3 mm/day	7.15 mm/day	-8.173 mm/day	30%	15 days	7.08 minute
Temperature	31 ^oC						
Radiation	39 %						
Wind speed	3.8 mph						

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK

5.1. CONCLUSIONS

The work presented in this thesis are automatic control plant watering system based on fuzzy logic controller.

The increasing of humidity and the decreasing of temperature, radiation and wind speed is led to increase the evapotranspiration and vice versa as illustrated Fig.4.7, Fig.4.9 and Fig.4.11. At high evapotranspiration value, the water requirement for the specific crop is high and vice versa. The evapotranspiration difference, the moisture value and the month after sowing have effects on the growing or farming of crops.

The duration of valve opening is gradually increased with the decreasing of Moisture value, mid-season of the crop sowing period and the decreasing of evapotranspiration difference. As illustrated in Fig.4.5, the values of the moisture is 59% (wet), the evapotranspiration difference is 2.22 small positive (SP) and the month after sowing is 20 days (initial stage) have been applied to the input variables of moisture, evapotranspiration difference and month after sowing respectively. The corresponding crisp output of the fuzzy logic on the duration of valve opening is 0.6 minute. As illustrated in Fig.4.6, the values of the moisture is 23.7% (dry), the evapotranspiration difference is large negative LN (-5.3), and the month after sowing is mid stage (82 days) have been applied to the input variables of moisture, evapotranspiration difference and month after sowing respectively. The corresponding crisp output of the fuzzy logic on the valve is 22.5 minute (V-long).

When the evapotranspiration difference is highly negative, the moisture value of the soil is dry and the month after sowing of the crop is in mid stage, the duration of valve opening was very long as illustrated in Fig.4.6. And also when the evapotranspiration difference is highly positive, the moisture value of the soil is wet and the month after sowing of the crop is in initial stage and late stage, the duration of valve opening was zero or very short as illustrated in Fig.4.5.

5.2. FUTURE WORK

Future research areas related to the plant watering system are listed below

- The fuzzy logic system was develop in this paper is for only one crop, no longer work for other crops. Therefore, the fuzzy system in this paper need to be improved to be applied for those other crops.
- This thesis work may be refined by considering exact measurement of environmental data at different local time.

REFFERENCES

[1] G. Kumar, “Water Irrigation by using wireless sensor network", *International Journal of Scientific Research Engineering & Technology*, 2014.

[2] F.Touati, M. Al-Hitmi and K.Behmed , "A fuzzy logic based irrigation managment system in arid regions applied to the state of Qatar," *Sustainable Irrigation and Drainage,* vol. IV, no. 189, November 2012.

[3] B. Stauffer and D. Spuhler, "Automatic Irrigation," SSWM University, 27 april 2018. [Online]. Available: http://www.sswm.info. [Accessed 15 may 2018].

[4] The Fedral Demotratic Repuplic of Ethiopia Centeral Stastical Agency, "Area and Production of Crops," vol.1, ADDIS ABABA, 2008.

[5] V.S.Rahagadale and D.S. Choudhary, "On Fuzzy Logic based Model for Irrigation Controller using penman-Monteith equation," *2nd National Conference on Information and Communication Technology*, Gondia, 2011.

[6] N. Siddique, “A Hybrid Approach Based on Fuzzy Logic,Neural Networks and Genetic Algorithms”, Switzerland: Springer International Publishing , 2014.

[7] R. Bellazzi, "Qualitative models and fuzzy systems:an integrated approach for learning from data," *Artificial Intelligence in Medicine,* vol. 14, no. 12, p. 5–28, 1998.

[8] Gunturi, V.N. Rohit, "Micro Controller Based Automatic Plant Irrigation System," *International Journal of Advancements in Research & Technology,* vol. 2, no. 4, pp. 2278-7763, 2013.

[9] Ruiz, J. Gutiérrez, and J. Fernández, "A fuzzy controller with an optimized defuzzification algorithm," *IEEE Micro,* vol. 11, no. 10, pp. 1-10, 1995.

[10] A. Mamdani, "An experiment in linguistic synthesis with a fuzzy logic controller," *International Journal of Man-Machine Studies,* vol. 7, no. 1, pp. 1-13, 1975.

[11] L. Zadeh, "Outline of a new approach to the analysis of complex systems and decision processes," *IEEE Transactions on Systems, Man, and Cybernetics,* vol. 3, no. 1, pp. 28-44, 1973.

[12] Car N. and Christen E., "Using a mobile phone Short Messaging Service (SMS) for irrigation scheduling in Australia Farmers’ participation and utility evaluation," *Computers and Electronics in Agriculture,* vol. 84, no. 3, pp. 132-143, 2012.

[13] Zhang, L. Bengtsson, L.Liao, "Soil moisture variation and waterconsumption of spring wheat and their effects on crop yield under drip irrigation," *Irrigation Drainage System*, vol. 5, no. 22, pp. 253–270, 2008.

[14] S.Tale and Sowmya p., "Intelligent Automatic Irrigation System," *(IJCSIT) International Journal of Computer Science and Information Technologies,* vol. 7, no. 1, pp. 141-143, 2016.

[15] V. R. Gunturi, "Micro Controller Based Automatic Plant Irrigation System," *International Journal of Advancements in Research & Technolog,* vol. 2, no. 4, pp. 2278-7763, April 2013.

[16] NASA, Clouds & Radiation Fact Sheet," [Online]. Available: https://earthobservatory.nasa.gov/Features/Clouds/clouds6.php. [Accessed 06 june 2018].

[17] Wallace, John, and Peter Hobbs. Atmospheric Science an Introductory Survey. 2nd ed. New York: Elsevier, 2006.

[18] Allen.R, "Crop Evapotranspiration Guidelines for Computing Crop Water Requirements," *FAO Irrig. Drainag.*, Rome, 1998.

[19] F. W. Murray, "On the computation of saturation vapor pressure," *J. Appl. Meteor,* vol. 6, pp. 203-204, 1967.

[20] M. El-Gayar, "Climate parameters used to evaluate the evapotranspiration in delta central zone of egypt," in *Fourteenth International Water Technology Conference*, Cairo, Egypt , 2010.

[21] R. G. Allen, "Reference evapotranspiration (ETo) and crop water requirement (ETc) of wheat and maize in Gujarat," *Journal of Agrometeorology*, vol. 1, no. 17, pp. 107-113, 2015

[22] National Metrological Service Agency at Assosa branch

[23] Pandey, R. Mehta and Vyas, "Reference evapotranspiration (ETo) and crop water requirement of wheat andmaize in Gujarat," *Journal of Agrometeorology,* vol. 1, no. 17, pp. 107-113, June 2015.

[24] Vrieling, A. de Leeuw, Jan Said, Mohammed Y., "Length of growing period over Africa," *variability and trends from 30 years of NDVI Time Series***.** *In: Remote sensing*,Vol. 5, No. 2. pp. 982-1000, 2013.

[25] Li, L., Tao, J., Wang, Y., Su, Y. et al., "Effects of Intake Valve Closing Timing on Gasoline Engine Performance and Emissions," SAE Technical Paper 2001-01--3564, 2001.

[26] T. A. Izzuddin, M. A. Johari, M. Z. A Rashid and M. H Jali, "Smart Irrigation Using Fuzzy Logic Method," *ARPN Journal of Engineering and Applied Sciences*, vol. 13, no. 2, pp. 1819-6608, 2018.

[27] A. Salam Al-Ammri, Sherin Ridah, " Smart Irrigation System Using Wireless Sensor Network," *International Journal of Engineering Research & Technology,* vol. 3, no.01, pp. 2278-0181, 2014.

[28] S. Muhammad Umair, R. Usman, "Automation of Irrigation System Using ANN based Controller" *International Journal of Electrical & Computer Sciences*, vol.10, no.02, pp. 104602-5757, 2010.

[29] G.Kokkonis, S.Kontogiannis, D.Tomtsis, "A Smart IoT Fuzzy Irrigation System" *IOSR Journal of Engineering*, vol.7, no.06, pp. 2278-8719, 2017.

[30] Obota, M. E., and H. C, "Soil moisture based irrigation control system for rice cropping using wireless sensor network" *The International Journal of Engineering and Science.* Vol.2, pp. 37-43. Inyama. 2013.

[31] S. Siva Sankari and G. Mary Jansi Rani, "A Wireless Monitoring and Controlling Automatic Irrigation Field", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 3, Issue 12, pp. 2278 – 8875, December 2014.

[32] R. Yan, H. Sun, and Y. Qian (2013) "Energy-aware sensor node design with its application in wireless sensor networks," *IEEE Trans. Instrum..Meas*., vol. 62, no. 5, pp. 1183–1191.

[33] L.L.Pfitscher "An automated irrigation system for rise cropping with remote supervision" proceeding of international conference on power engineering, energy and electrical devices, vol. 50, pp 90. , 2011.

[34] Xinrong Zhang, Bo Chang, "Design of Water saving irrigation Monitoring System Based on Fuzzy-PID," *Journal of Control Engineering and Technology (JCET),* vol. 2, no. 3, P. 124-129, 2012.

[35] Siddique, N. (2014). *A Hybrid Approach Based on Fuzzy Logic, Neural Networks and Genetic Algorithms.* United Kingdom: Springler.

[36] Kala, J., T.J. Lyons, I.J. Foster,U.S.,Nair, “Validation of a siple steady-state forecaste of minimum noctural tempratures”, *Journal of Applied metrology and Climatology*, vol. 48, P. 624-633, 2009.

APPENDIX

Appendix A: Fuzzy Systems

[System]

Name='maize'

Type='mamdani'

Version=2.0

NumInputs=3

NumOutputs=1

NumRules=60

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

[Input1]

Name='Moisture'

Range=[0 100]

NumMFs=3

MF1='dry':'trapmf',[-1 0 20 30]

MF2='medium':'trimf',[15 40 65]

MF3='wet':'trapmf',[50 60 100 101]

[Input2]

Name='Evapotranspiration-difference'

Range=[-10 10]

NumMFs=5

MF1='LN':'trapmf',[-11 -10.5 -7.5 -6]

MF2='SN':'trimf',[-7 -4 -1]

MF3='EQ':'trimf',[-1.5 0 1.5]

MF4='SP':'trimf',[1 4 7]

MF5='LP':'trapmf',[6 7.5 10.5 11]

[Input3]

Name='length-of-sowing-period'

Range=[0 140]
NumMFs=4
MF1='intial-stage':'trimf',[0 10 20]
MF2='dev-stage':'trimf',[15 40 65]
MF3='mid-stage':'trimf',[40 75 110]
MF4='late-stage':'trimf',[100 120 140]

[Output1]
Name='Duration-of-valve-opening'
Range=[0 30]
NumMFs=5
MF1='zero':'trimf',[0 0.5 1]
MF2='v-short':'trimf',[0.5 3 5.5]
MF3='short':'trimf',[3 7.5 12]
MF4='long':'trimf',[10 15 20]
MF5='v-long':'trimf',[18 24 30]

[Rules]
1 1 1, 4 (1) : 1
1 2 1, 4 (1) : 1
1 3 1, 3 (1) : 1
1 4 1, 2 (1) : 1
1 5 1, 1 (1) : 1
1 1 2, 5 (1) : 1
1 2 2, 5 (1) : 1
1 3 2, 4 (1) : 1
1 4 2, 3 (1) : 1
1 5 2, 2 (1) : 1
1 1 3, 5 (1) : 1
1 2 3, 5 (1) : 1
1 3 3, 4 (1) : 1
1 4 3, 3 (1) : 1
1 5 3, 2 (1) : 1
1 1 4, 4 (1) : 1
1 2 4, 4 (1) : 1

1 3 4, 3 (1) : 1

1 4 4, 2 (1) : 1

1 5 4, 1 (1) : 1

2 1 1, 2 (1) : 1

2 2 1, 2 (1) : 1

2 3 1, 1 (1) : 1

2 4 1, 1 (1) : 1

2 5 1, 1 (1) : 1

2 1 2, 3 (1) : 1

2 2 2, 3 (1) : 1

2 3 2, 2 (1) : 1

2 4 2, 1 (1) : 1

2 5 2, 1 (1) : 1

2 1 3, 3 (1) : 1

2 2 3, 3 (1) : 1

2 3 3, 2 (1) : 1

2 4 3, 1 (1) : 1

2 5 3, 1 (1) : 1

2 1 4, 2 (1) : 1

2 2 4, 2 (1) : 1

2 3 4, 1 (1) : 1

2 4 4, 1 (1) : 1

2 5 4, 1 (1) : 1

3 1 1, 1 (1) : 1

3 2 1, 1 (1) : 1

3 3 1, 1 (1) : 1

3 4 1, 1 (1) : 1

3 5 1, 1 (1) : 1

3 1 2, 2 (1) : 1

3 2 2, 1 (1) : 1

3 3 2, 1 (1) : 1

3 4 2, 1 (1) : 1

3 5 2, 1 (1) : 1

3 1 3, 2 (1) : 1

3 2 3, 1 (1) : 1

3 3 3, 1 (1) : 1

3 4 3, 1 (1) : 1

3 5 3, 1 (1) : 1

3 1 4, 1 (1) : 1

3 2 4, 1 (1) : 1

3 3 4, 1 (1) : 1

3 4 4, 1 (1) : 1

3 5 4, 1 (1) : 1

Appendix B: Fuzzy Rules

1) If (the moisture is dry) and (Evapotranspiration difference is LN) and (length of sowing period is Initial stage) then (duration of Valve opening is **long**)
2) If (the moisture is dry) and (Evapotranspiration difference is SN) and (length of sowing period is Initial stage) then (duration of Valve opening is **long**)
3) If (the moisture is dry) and (Evapotranspiration difference is EQ) and (length of sowing period is Initial stage) then (duration of Valve opening is **short**)
4) If (the moisture is dry) and (Evapotranspiration difference is SP) and (length of sowing period is Initial stage) then (duration of Valve opening is **v-short**)
5) If (the moisture is dry) and (Evapotranspiration difference is LP) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
6) If (the moisture is dry) and (Evapotranspiration difference is LN) and (length of sowing period is Dev-stage) then (duration of Valve opening is **v-long**)
7) If (the moisture is dry) and (Evapotranspiration difference is SN) and (length of sowing period is Dev stage) then (duration of Valve opening is **v-long**)
8) If (the moisture is dry) and (Evapotranspiration difference is EQ) and (length of sowing period is Dev stage) then (duration of Valve opening is **long**)
9) If (the moisture is dry) and (Evapotranspiration difference is SP) and (length of sowing period is Dev stage) then (duration of Valve opening is **short**)
10) If (the moisture is dry) and (Evapotranspiration difference is LP) and (length of sowing period is Dev stage) then (duration of Valve opening is **v-short**)
11) If (the moisture is dry) and (Evapotranspiration difference is LN) and (length of sowing period is Mid stage) then (duration of Valve opening is **v-long**)
12) If (the moisture is dry) and (Evapotranspiration difference is SN) and (length of sowing period is Mid stage) then (duration of Valve opening is **v-long**)
13) If (the moisture is dry) and (Evapotranspiration difference is EQ) and (length of sowing period is Mid stage) then (duration of Valve opening is **long**)
14) If (the moisture is dry) and (Evapotranspiration difference is SP) and (length of sowing period is Mid stage) then (duration of Valve opening is **short**)
15) If (the moisture is dry) and (Evapotranspiration difference is LP) and (length of sowing period is Mid stage) then (duration of Valve opening is **v-short**)
16) If (the moisture is dry) and (Evapotranspiration difference is LN) and (length of sowing period is late stage) then (duration of Valve opening is **long**)

17) If (the moisture is dry) and (Evapotranspiration difference is SN) and (length of sowing period is late stage) then (duration of Valve opening is **long**)
18) If (the moisture is dry) and (Evapotranspiration difference is EQ) and (length of sowing period is late stage) then (duration of Valve opening is **short**)
19) If (the moisture is dry) and (Evapotranspiration difference is SP) and (length of sowing period is late stage) then (duration of Valve opening is **v-short**)
20) If (the moisture is dry) and (Evapotranspiration difference is LP) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)
21) If (the moisture is medium) and (Evapotranspiration difference is LN) and (length of sowing period is Initial stage) then (duration of Valve opening is **v-short**)
22) If (the moisture is medium) and (Evapotranspiration difference is SN) and (length of sowing period is Initial stage) then (duration of Valve opening is **v-short**)
23) If (the moisture is medium) and (Evapotranspiration difference is EQ) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
24) If (the moisture is medium) and (Evapotranspiration difference is SP) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
25) If (the moisture is medium) and (Evapotranspiration difference is LP) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
26) If (the moisture is medium) and (Evapotranspiration difference is LN) and (length of sowing period is Dev stage) then (duration of Valve opening is **short**)
27) If (the moisture is medium) and (Evapotranspiration difference is SN) and (length of sowing period is Dev stage) then (duration of Valve opening is **short**)
28) If (the moisture is medium) and (Evapotranspiration difference is EQ) and (length of sowing period is Dev stage) then (duration of Valve opening is **v-short**)

29) If (the moisture is medium) and (Evapotranspiration difference is SP) and (length of sowing period is Dev stage) then (duration of Valve opening is **zero**)
30) If (the moisture is medium) and (Evapotranspiration difference is LP) and (length of sowing period is Dev stage) then (duration of Valve opening is **zero**)
31) If (the moisture is medium) and (Evapotranspiration difference is LN) and (length of sowing period is Mid stage) then (duration of Valve opening is **short**)
32) If (the moisture is medium) and (Evapotranspiration difference is SN) and (length of sowing period is Mid stage) then (duration of Valve opening is **short**)
33) If (the moisture is medium) and (Evapotranspiration difference is EQ) and (length of sowing period is Mid stage) then (duration of Valve opening is **v-short**)
34) If (the moisture is medium) and (Evapotranspiration difference is SP) and (length of sowing period is Mid stage) then (duration of Valve opening is **zero**)
35) If (the moisture is medium) and (Evapotranspiration difference is LP) and (length of sowing period is Mid stage) then (duration of Valve opening is **zero**)
36) If (the moisture is medium) and (Evapotranspiration difference is LN) and (length of sowing period is late stage) then (duration of Valve opening is v-short)
37) If (the moisture is medium) and (Evapotranspiration difference is SN) and (length of sowing period is late stage) then (duration of Valve opening is **v-short**)
38) If (the moisture is medium) and (Evapotranspiration difference is EQ) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)
39) If (the moisture is medium) and (Evapotranspiration difference is SP) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)
40) If (the moisture is medium) and (Evapotranspiration difference is LP) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)

41) If (the moisture is wet) and (Evapotranspiration difference is LN) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
42) If (the moisture is wet) and (Evapotranspiration difference is SN) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
43) If (the moisture is wet) and (Evapotranspiration difference is EQ) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
44) If (the moisture is wet) and (Evapotranspiration difference is SP) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
45) If (the moisture is wet) and (Evapotranspiration difference is LP) and (length of sowing period is Initial stage) then (duration of Valve opening is **zero**)
46) If (the moisture is wet) and (Evapotranspiration difference is LN) and (length of sowing period is Dev stage) then (duration of Valve opening is **v-short**)
47) If (the moisture is wet) and (Evapotranspiration difference is SN) and (length of sowing period is Dev stage) then (duration of Valve opening is **zero**)
48) If (the moisture is wet) and (Evapotranspiration difference is EQ) and (length of sowing period is Dev stage) then (duration of Valve opening is **zero**)
49) If (the moisture is wet) and (Evapotranspiration difference is SP) and (length of sowing period is Dev stage) then (duration of Valve opening is **zero**)
50) If (the moisture is wet) and (Evapotranspiration difference is LP) and (length of sowing period is Dev stage) then (duration of Valve opening is **zero**)
51) If (the moisture is wet) and (Evapotranspiration difference is LN) and (length of sowing period is Mid stage) then (duration of Valve opening is **v-short**)
52) If (the moisture is wet) and (Evapotranspiration difference is SN) and (length of sowing period is Mid stage) then (duration of Valve opening is **zero**)
53) If (the moisture is wet) and (Evapotranspiration difference is EQ) and (length of sowing period is Mid stage) then (duration of Valve opening is **zero**)
54) If (the moisture is wet) and (Evapotranspiration difference is SP) and (length of sowing period is Mid stage) then (duration of Valve opening is **zero**)
55) If (the moisture is wet) and (Evapotranspiration difference is LP) and (length of sowing period is Mid stage) then (duration of Valve opening is **zero**)
56) If (the moisture is wet) and (Evapotranspiration difference is LN) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)

57) If (the moisture is wet) and (Evapotranspiration difference is SN) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)
58) If (the moisture is wet) and (Evapotranspiration difference is EQ) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)
59) If (the moisture is wet) and (Evapotranspiration difference is SP) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)
60) If (the moisture is wet) and (Evapotranspiration difference is LP) and (length of sowing period is late stage) then (duration of Valve opening is **zero**)

Appendix C: Matlab function of actual evapotranspiration

```
function ET0  = fcn(h, t, r, w)

% t= temperature

%r= net radiation

%h= relative humidity

%w= wind speed at 2m height

%d= Slope vapor pressure curve

%es= Saturation vapor pressure

%ea= actual vapor pressure

%g= Psychometric constant

d =0.00021501*t^2-0.00025132*t+0.061309

es=7.167*10^(-5)*t^3+7.167*10^(-4)*t^2+0.061309*t+0.57075

ea=es*h/100

g=1.005*101.3/(0.622*(2.51-0.00236*t))

ET0=(0.408*d*0.9*r+g*900/(t+273)*w*(es-ea))/(d+g*(1+0.34*w))
```